From Dying Stars to the Birth of Life

The new science of astrobiology and the search for life in the universe

Jerry L Cranford

Nottingham University Press

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Nottingham University Press
Manor Farm, Main Street, Thrumpton
Nottingham, NG11 0AX, United Kingdom

NOTTINGHAM

First published 2011

British Library Cataloguing in Publication Data
From Dying Stars To The Birth Of Life -
The New Science of Astrobiology and the Search for Life in the Universe

ISBN 978-1-907284-79-3

Typeset by Nottingham University Press, Nottingham
Printed and bound by Gutenberg Press Ltd, Malta

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PREFACE

The present author is not a professional astronomer. My formal educational training (Ph.D) was in psychology and the neurosciences. While astronomy was my lifelong hobby, my career involved teaching university graduate school classes plus conducting brain research studies. Although I definitely enjoyed my job as a professor and researcher, there were a few occasions, especially in more recent years when the field of astronomy began witnessing a number of exciting new discoveries, that I did experience a few fleeting moments of regret for not having chosen this field as my primary vocation. In 1964 when I had to make a choice between pursuing a professional career in psychology and the brain sciences or to upgrade my childhood fascination with the stars and planets to the level of a fulltime occupation, I opted for the former. It seemed that being an amateur astronomer would likely make more sense than trying to be an amateur brain scientist. For purposes of supporting a hobby, backyard telescopes are much more practical and far less expensive than brain research laboratories (plus probably being more socially acceptable). So, for the next 37 years, I was by day a college professor and by night an amateur star gazer.

What I did not know in 1964 was that the field of astronomy was on the threshold of a genuine ***scientific revolution*** that could possibly, perhaps well before the end of the 21st century, finally provide mankind with the first definitive evidence that we are not alone in the universe. This sudden breakthrough in astronomy is but one of many incredible advances in virtually all of the scientific fields (as well as non-sciences) that resulted from the sudden and dramatic explosion of digital computers onto the world stage in the latter half of the 20th century. Astronomers now had for the first time the tools they needed to begin making the huge leap from only being able to speculate and fantasize about the possibility of life on other worlds to actually being able to determine whether such life actually exists. In 1964, most astronomers thought that the occurrence of other solar systems that might harbor life friendly planets was an extremely rare event. By the end of the 20th century we were well on our way to confirming that other planetary systems not only exist but may actually be quite common in our incredibly vast universe. Many space scientists now believe that possibly as many as one-fifth to one-half of all sun-like stars in the universe may host planetary systems, and many of these stars may have earth-like worlds circling them.

In 1964 most life scientists also believed the evolution of life was an extremely complicated and fragile process that demanded equally complex and fragile environmental conditions to allow it to happen. By the end of the 20th century our life scientists had made two amazing discoveries that seemed to challenge this long held belief. The first was the finding that life

apparently had been able to develop on earth almost as soon as the extremely hot and violent planetary formation process had settled down sufficiently to allow liquid water to exist on our planet's surface. Also, in the 1970s, scientists suddenly began discovering strange single-celled bacterial-like organisms living and thriving in extreme hostile environments that would be fatal to today's "normal" life-forms. Many of these creatures, which are now labeled by the scientists as *extremophiles* (which means "lovers of extreme environments") appear to be the direct descendents of the first living organisms that originated a little less than four billion years ago shortly after the earth was formed. One of the first of these bizarre life-forms to be discovered actually live in extremely hot environments located deep in the oceans where superhot molten lava is escaping from the hot interior of the earth, and also in the boiling hot geysers at Yellowstone National Park and other hot springs locations. Scientists have appropriately dubbed these organisms as *thermophiles* (i.e. "lovers of hot environments"), or even *hyperthermophiles* (for those that actually live in *boiling* water). In more recent years, scientists have discovered many additional varieties (species) of these life-forms that appear to prefer to live in other kinds of hostile environments including extremely cold (or hot) deserts that are almost totally dry, in frozen ice bergs, inside rocks located miles below ground, in extremely salty, acidic, or alkaline waters, or on the top of high mountains where there is very little air and they are constantly bombarded by deadly ultraviolet radiation from the sun. Others have even been found living in the coils of nuclear reactors where they are constantly exposed to deadly levels of radiation.

Many scientists now actually believe that some of earth's extremophiles might even be able to survive in other extreme environments that we now believe may exist on other planets (Mars) or even the moons of some planets (e.g. Jupiter's moon Europa) in our own solar system. The discovery of these incredibly "tough" critters that make the rest of us so-called normal earthlings look like total "wimps", has now convinced many scientists that life, even on our own planet, is far more tenacious and resilient than anyone would have believed possible just a few short years ago. This suggests that life might also be able to easily evolve on other worlds in the universe that offer reasonable, or perhaps not so *reasonable*, chemical and physical living accommodations. The possibility that life might be a common feature of our universe, plus the fact that "homes" for such life-forms may be plentiful in the universe, quickly led to the birth of a new interdisciplinary field of science known as ***Astrobiology***. This new science is now attracting a rapidly growing number of very competent and distinguished research scientists from the traditional earth (geology), space (astronomy), and life (biology) sciences to join ranks in launching major new research programs to investigate how life developed on our planet and how (and where) life may develop on other worlds in the universe,

Therefore, by the time I was ready, in 2008, to retire from my long career as a university professor and brain scientist, my lifelong astronomy hobby had literally skyrocketed into being science's "hottest new show in town". Upon returning home from my retirement dinner, I immediately self-proclaimed myself as now a ***fulltime*** amateur astrobiologist and dove head

first back into the love of my youth, that of astronomy and related topics. Having developed a passion for writing (both research journal articles and textbooks) while a college professor, I decided to launch my retirement years by writing a basic introductory level book for interested non-scientists on this exciting new field of Astrobiology. I firmly believe that the recent flood of important new scientific discoveries related to the possibility of life on other worlds must be made known to the interested non-science public, as they may very soon (perhaps in our own lifetimes) profoundly affect how we view ourselves and our world. Hopefully, discovering that we are not alone in the universe will help mankind to better appreciate that life everywhere is precious and must be protected and cherished.

Finally, the present author must acknowledge a few people who stood by, tolerated, or otherwise provided much needed support and encouragement while I went through the emotional highs and lows of writing this book. However, before doing that, I must first get something "off my chest". It is important that the readers know that I absolutely cannot take any credit for any of the scientific information that this book contains. As an amateur astronomer I made absolutely no contributions to the knowledge base of this very exciting scientific field. ***I took but never gave back***! I am hoping that this book might allow me to make at least some small amends to my shortcoming by possibly motivating a few young readers to choose this field as their lifelong occupation. Now, for my "thank yous". First, I must thank Luca Bombelli at the University of Mississippi for helping me track down some of the sources for the information I wanted to include in this book, as well as sending me some publications that contained vital information. Seth Shostak at the SETI Institute also was kind enough to look over and give me valuable suggestions on a draft of a section of Chapter 6 where I described the exciting search for extraterrestrial life that he and his colleagues in Mountain View, California have been engaged in for many years. Also, my next door neighbor and friend, Katharine Judson Rose, who is a physician, was kind enough to read an earlier draft of my book, and especially Chapter 3 ("How Life Works on Earth") to make sure it contained no snafus or errors related to medical or biological matters. Throughout the two years that I worked my tail off on the manuscript, the father/son duo of Richard and Julian Baum in England provided much needed encouragement and support. Julian, who is a superb space artist, provided an absolutely beautiful illustration for the book (see Figure 2-34), while Richard who, like me, is a lifelong amateur astronomer (but quite accomplished being a Fellow of the Royal Astronomical Society of Britain, an author of some excellent astronomy history books, plus having an asteroid named after him) kindly served as my confidant and sounding board as I faced the occasional frustrations of preparing the book. Also, Sarah Keeling at Nottingham University Press, who says she is not an artist, did an excellent job of drawing Figure 3-7 for me. Thanks, Sarah. Finally, I absolutely must thank my wife for standing by me as I went through the insanities of authorship plus also totally flipping my sleep schedule to being that of a night owl.

CHAPTER I

COMPUTERS, ROCKET SCIENCE, AND THE BIRTH OF ASTROBIOLOGY

The invention of integrated electronic circuits and digital computers in the late 1950s, while initially considered as nothing more than another interesting science trick or novelty by many of us, was without doubt one of mankind's greatest achievements since his discovery of fire and the hammering out of the first stone tools. Within a very short time, this new technology would begin to totally transform the world as we know it. At least for the scientific minded among us, computers now seemed to be mankind's ticket to achieving our wildest dreams and fantasies for a better and happier future for the human race. Digital computers quickly became mankind's primary tool for dramatically increasing our knowledge and enhancing our technologies in virtually all fields of the sciences as well as the non-sciences. In the present book, the author will tell the fascinating story of how computers have now brought us to the point of possibly discovering that we are not the only living creatures in the universe.

Mankind's Obsession with the Idea that we are Not Alone in the Universe

The idea that life might exist on worlds other than our own has been with us from the time of our cave dwelling ancestors. However, for thousands of years, while humans had no means except their two unaided eyeballs to allow them to collect any evidence for the existence of such other worldly life-forms, man's prolific imagination was more than adequate to the task of filling in this gap. Science fiction writers have never ended their careers on the streets having to beg for their next meal, and Hollywood actors and movie producers have always been able to ride in fancy limousines as compensation for their blockbuster space monster flicks. In 1938, later-to-be Hollywood actor and legend Orson Welles even discovered it was dangerous to broadcast a fictional radio show in a Halloween stunt that was made to resemble a live newscast announcing the invasion of rural New York and New Jersey by monsters from the planet Mars. Numerous people all over the east coast (as well as other parts of the United States), who were listening

to the radio broadcast, immediately panicked and began jamming emergency telephone switchboards and going to churches to get their spiritual affairs in order. The widespread panic that this radio show created made the front page headlines of newspapers all over the world the next morning. After the invention of the telescope, while man discovered that other planets do exist in outer space, we still had no means of knowing whether any of these places might be inhabited by living beings. But, again, science fiction writers and passionate scientists filled in the gaps. For example, in 1900, Percival Lowell, a millionaire business man turned amateur astronomer, dipped deeply into his own pockets and built a very large state-of-the-art telescope (that is still in operation today) and began observing the planet Mars from an observatory on a mountain top near Flagstaff, Arizona. Lowell quickly observed what he believed was a system of irrigation canals built by a race of Martians who were trying to save their rapidly drying up planet by channeling melting water from the polar icecaps to their farms located closer to the planet's equator (Figure 1-1). Night after night, Lowell strained his eyes through the telescope and meticulously made detailed hand drawings of the complex system of canals he was convinced he saw. These observations and drawings were not intended to be a hoax or a publicity stunt. Lowell was a competent astronomer who simply misinterpreted what he was seeing.

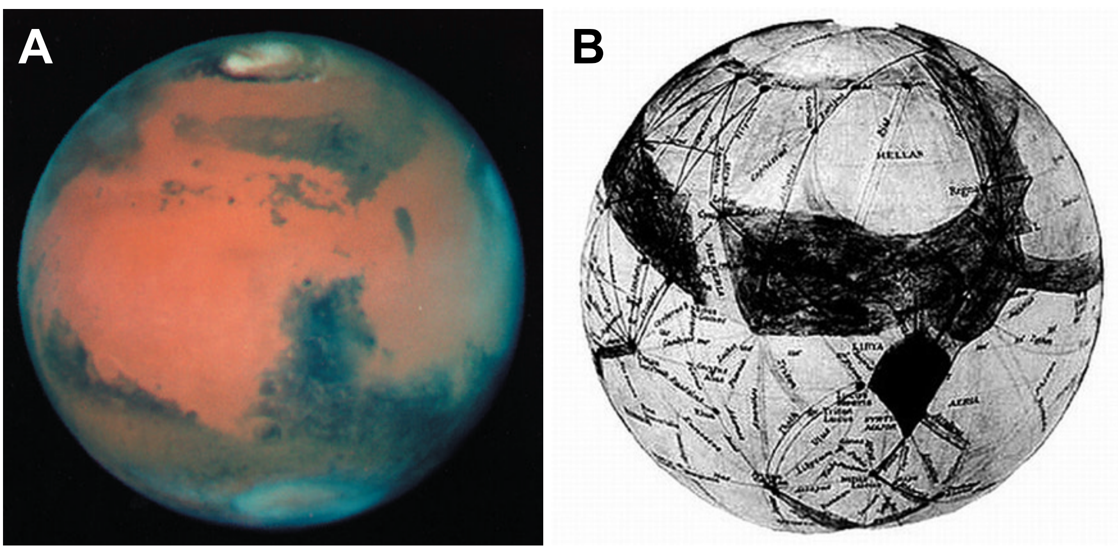


Figure 1-1 - In 1900, Percival Lowell believed he was seeing irrigation canals built by Martian farmers when he viewed the planet Mars with a telescope. **A** shows a photo of Mars taken by the Hubble space telescope (Image credit: David Crisp/JPL/NASA), while **B** shows one of Lowell's hand drawn maps of the system of canals he thought he saw. (Image credits: NASA)

The relatively recent advent of computers and the birth of the space age have begun to quickly and profoundly transform the world as we know it. The last half of the 20th century fostered numerous important advances in many scientific fields but, in the areas related to the possibility of life on planets other than our own, a virtual explosion of new and

mind boggling scientific findings has been unleashed. Especially exciting is the emergence of an entirely new inter-disciplinary field of science which is bringing together the best scientific minds in the fields of the earth sciences (geology, geophysics/geochemistry), the life sciences (genetics, evolution, and biochemistry/origin of life), the space sciences (astronomy, planetary science, rocket science), and even (yes!) the behavioral sciences (sociology, psychology, neuroscience). This new expanded mega-discipline was first labeled "exobiology", but after the mid to late 1990s, it has become better known as ***Astrobiology***. That this new field of science has finally arrived on the scene to stay is evidenced by the fact that, starting shortly after the year 2000, a rapidly growing number of distinguished universities worldwide started offering Ph.D training programs in this field (e.g., Pennsylvania State University, University of California, Los Angeles, University of Washington, University of Arizona, University of Colorado in the United States; The Canadian Astrobiology Training Program, a joint program involving several distinguished Canadian universities; Stockholm University in Sweden; University of Glamorgan in the United Kingdom, and the University of New South Wales in Australia). Several additional universities that offer Ph.D training (i.e. as a "major" area of academic training) in the traditional field of astronomy also now make it possible for students to "minor" in astrobiology. Although scientists have not yet obtained definitive proof of either the existence or the absence of extraterrestrial life (i.e., life on other worlds), a virtual mountain of new scientific discoveries have been made since the early 1950s that provide strong indirect evidence that life may be a common outcome of normal physical and chemical processes in appropriate environments throughout the universe. In the present book, the author will describe and summarize this new evidence in a format which will, hopefully, be easy for general readers (non-scientists) to comprehend. Plain old English descriptions will be used instead of technical jargon as much as possible. When important scientific concepts dictate the use of unfamiliar technical terms, I will insert brief written explanations/clarifications (plus special illustrations, when needed) into the text along with references to simplified published explanations by experts on the topic. In the following paragraphs, I will provide a series of brief summarizations of the contents of each of the chapters of the present book.

BRIEF OVERVIEW OF WHAT THIS BOOK IS ALL ABOUT

Chapter 2 will describe the current state of knowledge of the structure of the known universe, with an emphasis on those aspects that are most directly related to the possible occurrence of extraterrestrial life. The advent of the computer age and the space age in the second half of the 20th century opened a huge door for the rapid development of numerous high technology measuring instruments and tools that allowed scientists to

begin unraveling the mysteries of the universe at a rate never before seen in the history of mankind. Powerful new ground-based optical telescopes (e.g., the Mt. Palomar and Keck Observatories) were developed and configured with special computer-controlled *adaptive optical systems* that allowed man to see further into space than ever before, as well as eliminate large amounts of the interference from a turbulent and increasingly dirty atmosphere that had always hindered observations from telescopes located on the ground (or even mountain tops). Finally, again thanks to computers, scientists (and engineers) also invented new types of telescopes that allowed them to see much more than just the visible parts of the total light spectrum that our eyes were designed by nature to process. Special telescopes were built and launched into space that could collect light from stars or other celestial objects that emit or reflect longer (e.g., infrared, microwave, and radio) or shorter (ultraviolet, X-ray, gamma ray) wavelengths or frequencies of light energy that astronomers could now examine for new information. Many of the wavelengths other than visible light are normally blocked by the atmosphere, so that space based telescopes were necessary to allow these unique observations (Figure 1-2).

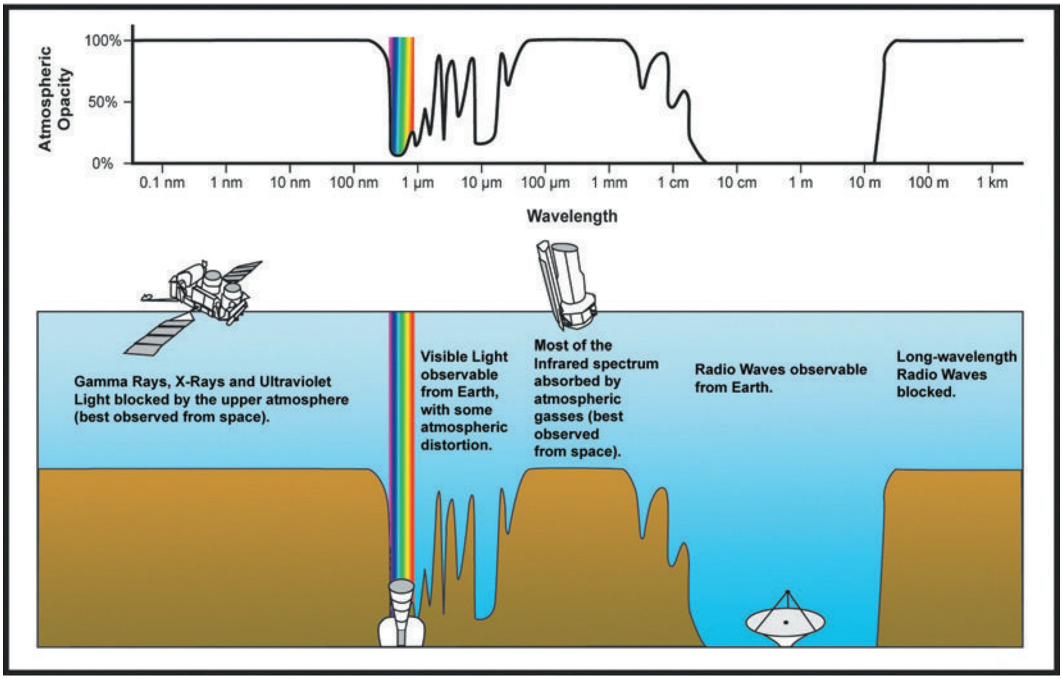


Figure 1-2 - Depicts the parts of the total electromagnetic light spectrum that are invisible from earth because the light is blocked by the atmosphere. Most of the visible portion of the spectrum can be seen from the surface, although somewhat distorted. The very short wavelength gamma ray, x-ray, and ultraviolet parts of the spectrum are totally blocked by the atmosphere as is the infrared and longer radio waves. (Image credit: NASA/IPAC)

As will also be described in chapter 2, the incredible amount of important new information that has been obtained with space telescopes has been one of the key advances that led scientists to believe that outer space may be considerably more "life friendly" than was thought to be the case prior to 1950. The new space telescopes allowed our astronomers for the first time to see stars and other celestial objects in a "totally different light" (i.e., the normally invisible parts of the electromagnetic light spectrum). With respect to the primary theme of the present book, the author firmly believes that the single most exciting and significant discovery that the new space age tools allowed is an answer to the profound question of "***Where is the chemical stuff of life created***". These new tools quickly provided our scientists with incredible evidence that the complex chemical materials or "building blocks" (i.e., the organic molecules that our bodies are made of) that are required to construct living things are constantly being manufactured inside gas and dust clouds that are located in the vast regions between the stars. The products of these remarkable *interstellar chemical factories* are then added to the fabric of the gas and dust clouds from which planetary systems are later built. When the gas and dust clouds begin collapsing and forming the rotating disks that will produce planets, these life critical chemicals are delivered by meteors and other rocky objects to the surfaces of the growing planets.

Also, in chapter 2 and again in chapter 5, the author will trace the exciting new story of the ***Planet Hunters***. In the 1950s, when I was just beginning my lifelong romance with astronomy, the prevailing viewpoint of astronomers was that the occurrence of planetary systems like ours (i.e., the sun and the other planets, including earth) was an extremely unlikely or rare event in the universe. Our solar system was thought to be the result of a rare close encounter between our sun and some other star that just happened by chance to wander into our neighborhood. The other star did not collide head on with our sun but came close enough that the two stars grazed each other which resulted in some of the material from our sun being torn away to form a cloud of debris that began to orbit around (i.e., circle) the sun and eventually condense into a family of planets. Since the average distance between any two stars in our region of the universe is incredibly large, the probability of any two stars colliding is virtually zero. Therefore, if this earlier theory of solar system formation had turned out to be accurate, the possibility of other earth-like planets that might allow life would be very improbable. However, as of 1995, astronomers discovered the first evidence of a planet (i.e., ***exoplanet***) circling another star. This was followed rapidly by the discovery of a second planetary system, then another, then yet another, until at the time of this book's writing (Fall, 2010), we have reached a virtual "planet of the week" mode of discovery, and the total number of exoplanets in other solar systems has now grown to 490, and this is for just the stars located in our immediate neighborhood of the universe. Thus, it seems planetary systems may be quite common in the universe.

By the end of the 20th century, astronomers had also confirmed that it is the horrific explosions (known as *supernovas*) that the largest stars undergo at the ends of their normal life spans that provides the heavier atomic elements (such as carbon, iron, oxygen, nitrogen, and even the heaviest elements like uranium) that are needed to construct planets as well as life. These heavier elements are created by the fusing together of lighter elements such as hydrogen and helium deep in the extremely hot interiors (*cores*) of these stars and then, when the star dies (explodes), they are violently ejected out into the surrounding interstellar spaces where they become a part of the gas and dust clouds which then provide the raw materials needed to build both planets and living creatures. *Therefore, several billion years ago, a giant star somewhere in our galaxy had to "die" in order for the reader and the author to be alive today!* Thus, science now tells us that all life on earth really is made of "star dust".

Finally, Chapter 2 will also describe the important contributions that have been made to our knowledge of both our planetary system and the universe by rocket science. Beginning at the end of the 1960s, and continuing at a rapidly accelerating rate to the present, the United States and Russia, joined later by our European colleagues (plus, more recently, China, India, and Japan), have been launching space observation satellites into orbit around the earth (to get above the interfering effects of the atmosphere), and also unmanned robotic missions to numerous celestial locations in our solar system. Multiple unmanned space probes (rockets) have been made to pass close by or, in some cases go into orbit around several of the inner (e.g., Mercury, Venus, Mars) and outer planets (Jupiter, Saturn, Uranus, and Neptune) to perform close up observations (photographs taken at different regions of the electromagnetic light spectrum, radar images of the surface, spectroscopic studies of the chemical makeup of planetary atmospheres and surfaces, etc.). Other probes have been made to land on the surfaces of various planets (Venus, Mars, and one of the moons of Saturn) to conduct much closer examinations.

In Chapters 3 and 4, I will tackle the sometimes socially or culturally sensitive issues related to the origins and development of life on planet earth. While the present book is primarily focused on reviewing the scientific evidence related to the possible existence of life on other worlds, it is a fact that the only life we have any knowledge of is earth life. This is a double edge sword. The only life we can study is carbon based life "as we know it". However, numerous investigations of earth life performed in the last half of the 20th century has convinced a rapidly growing number of scientists that life is not only very complex but may also be very flexible, and capable of arising more easily than previously thought possible. In Chapter 3, I will list and describe each of several major characteristics that collectively seem to distinguish between living matter and non-living matter. It will be seen that it is virtually impossible to come up with a simple definition of life that can be used to separate life from non-life. All of the different distinguishing features that scientists have listed as being characteristic of life do not always occur in every living creature and,

likewise, it is not uncommon for some forms of non-living matter to exhibit, in some unique circumstances, characteristics which we would normally consider as being specific to life. Incredibly, if the last half of the 20^{th} century has taught our life scientists anything, it is the phenomenal fact that ***the more we learn about how earth life works, the more we come to believe that life and non-life may not be nearly as different as we have for so long thought to be the case.*** Medical science is now well on its way to reaching a stage in which life and non-life may actually merge. Prosthetic (artificial) limbs and joints are here to stay, and the realities of the 1970s television shows depicting the bionic man or woman may not be that far away. *I, myself, as a hearing scientist (and also a licensed clinical audiologist), has seen first-hand the rapid development of artificial electronic ears (cochlear implants) to restore hearing in human patients*. Computers may eventually become interfaced with human brain circuits to give us "super mental powers" (or turn us into monsters). This merger of life and non-life on planet earth will no doubt make it more difficult to search for and recognize life-forms on other planets. Should we be looking for "little green men" or robotic machines capable of thinking, replicating, and evolving that ancient dying carbon-based life-forms may have invented and unleashed eons ago into the universe to carry on their legacy (as suggested by John von Neumann, circa 1968)?

In the beginning, earth was a hot hostile ball of rock and poison gases - now it is a very life friendly *biosphere* that is teeming with life. Another science lesson acquired in the last half of the 20^{th} century is that ***the specific forms that life takes may be very much associated with the nature of the environment in which it occurs***. Thus, extraterrestrial life may very well turn out to be, as espoused by many scientists, "life as we DO NOT know it". However, since earth life is, at present, all we have to study, we must focus on the intricacies of how life originated and developed (evolved) on our planet. Hopefully, this will provide us with important clues as to how life could develop on other worlds and, ***most importantly, why life might be different on other worlds.*** Of course, this intense study of earth life may bias our attempts (put blinders on us) with respect to speculations regarding the nature of other life-forms. Thus, Chapter 4 of this book will include a basic summarization of our current understanding of the history of life on earth, as well as the related topic of how the earth itself ***co-evolved*** with life to become quite life friendly. The history of life and the history of planet earth cannot be separated. Both biologists (life scientists) and geologists (earth scientists) must be involved in this research if we ever hope to have a complete understanding of this complicated subject matter. Therefore, Chapter 4 will, of necessity, combine a very diverse combination of information from a multitude of scientific fields, including astronomy, geology, organic chemistry (e.g., chemistry of life or biochemistry) and non-organic chemistry (e.g., chemistry of non-living matter such as rocks, minerals, water), paleontology (study of fossils), genetics, evolution, etc. This is the definite strength and, at the same time, the headache of the new multi-disciplinary field of astrobiology. I again promise to try to keep the bar as low as possible with respect to the

usage of technical terms and jargon, but may again need to ask the reader to bear with my attempts to explain or clarify any important but confusing information.

An additional very important part of Chapter 4 will be devoted to describing not only how earth and biology co-evolved to allow the emergence of life, but also will summarize the many ways in which both life and earth are very fragile and could be wiped out in the blink of an eye. Repeatedly, in the long history of life on earth, life came under the threat of possible total destruction. In just the last half billion years alone, there were at least five major mass extinction events in which life was almost terminated on our planet. Severe geologic- or cosmic-related catastrophes including being hit by lethal doses of radiation from nearby exploding stars (supernovas), plus sudden outbursts of severe volcanic activity, global warming and global freezing events occurred as well as collisions between the earth and large asteroids or comets from space. The evolution of life itself was drastically changed by these catastrophic events. The most recent event, which occurred a *mere* 65 million years ago, destroyed the dinosaurs which allowed man to evolve. However, a growing number of scientists are now beginning to believe that mass extinctions may be both a curse and a blessing - while being a major threat to the continuation of life, such catastrophes may be a strong ally of life in actually triggering major evolutionary processes that act to expand and diversify life. Unfortunately, earth is now once again undergoing a major mass extinction event, and this time it may be life's enemy rather than ally. Life is being destroyed everywhere due to man's pollution of his environment, the destruction of entire forests, and mankind's indifference to what the future may hold for their descendents. Astronomers tell us that, if left alone, planet earth could remain a quite pleasant place for all creatures for possibly another billion years. At his present pace, man may kill the planet in a few thousand years, or less. ***The present author, as both a scientist and a concerned resident of our planet, believes he absolutely must, in the present book, include a summary of these man-made threats to the future of life on earth since they are very real and very serious!***

In Chapters 5 and 6, I will focus on the fascinating topics related to searching for other worlds and other life-forms plus possibly either visiting or communicating with these fellow residents of our universe The incredible size of our universe will undoubtedly delay any efforts to launch manned space missions to such locations for quite some time, but the tenacity and stubbornness of our "rocket scientists" with the aid of scientists in other related fields (e.g., physics) could eventually prevail and allow mankind to find a way to make such trips. In Chapter 6, I will also describe the new scientific tools that our scientists have now developed to confirm the existence of potentially life-friendly exoplanets plus conduct searches for artificial signals (e.g., radio or laser light transmissions) that advanced civilizations may be inadvertently leaking into space or even deliberately sending our way for purposes of announcing their presence and/or opening up lines of communication. Although still a very controversial topic, I will also, in Chapter 6, discuss the possibility that

earth may have been visited in the past, or is currently being visited, by either unmanned or manned spacecraft from extraterrestrial civilizations.

Finally, in Chapter 7, the author will present some of his own personal thoughts and beliefs on the larger issue of the future of mankind in the universe. Having been a citizen of planet Earth for 67 years, an amateur astronomer for close to 57 years, and a trained scientist for almost 40 years, I do have some ideas, opinions, and possible insights into where mankind may be heading. A growing number of space and life scientists have, during the past 50 some years, started to believe that life, and possibly even intelligent life, may be far more common in the universe than most of us would have dared imagine prior to the advent of the computer and space age during the last century. Some serious scientists have even started asking the profound questions of, if the universe is so crowded with intelligent life-forms, "*Where are they?*" and "*Why have they not contacted us or somehow revealed their presence?*" Unfortunately, a growing number of concerned scientists have also begun to believe that the evolution of intelligent life may be highly correlated with the rise of the technological means by which such life-forms could accidentally or intentionally inflict self-destruction upon themselves before they are able to reveal themselves or contact other civilizations. If this is true, the universe may harbor more post-cataclysmic dead worlds than locations of vibrant cultural and technological activity. Sadly, I (largely because of my psychology and brain science background) share this fear with my science colleagues. Having grown up during the tumultuous Cold War years and now living in a world filled with threats of war and terrorism and in a recently hurricane devastated city that is struggling with a crime rate that is almost totally out of control, I firmly believe mankind must change in order to survive. In Chapter 7, I will discuss the huge chasm that exists between what man's focused scientific and cultural endeavors could offer us, and what his uncontrolled human nature may destroy.

CHAPTER II

OUR VAST AND HOSTILE LIFE-FRIENDLY UNIVERSE

Before beginning a description of the current state of our knowledge of the universe, I will take the reader on a brief trip through the long history of astronomy. This history is a fascinating and extremely interesting saga in and of itself, but the present description will be limited only to the high points.

Brief History 1 - In the Early Days, Seeing was Believing

For thousands of years, whenever looking at the nighttime sky with its vast splendor of stars and other bright objects (made easier in earlier days by the absence of city lights and smog), humans had only their naked eyes to provide any evidence as to what these objects were. Some individuals with curious minds and lots of free time on their hands quickly noticed that the different objects (moon, sun, stars) seemed to change their positions in the sky over intervals of time in a very regular and predictable manner. These first astronomers began the incredibly difficult task of systematically observing and recording the specific nature of these position changes and movements over time. To assist them in this task, these individuals invented and utilized special handmade instruments (**Figure 2-1**) that would allow them to gather accurate measurements of the positions or position changes of particular stars or other objects in the sky. The exact same measurements (for example, measuring the angle between a particular star and a fixed reference point on the horizon) had to be repeated over and over again at a series of specific times each day or night and also repeatedly at a series of specific monthly times each year. This work was extremely tedious and time consuming. After collecting what amounted to mountains of data over long periods of time (frequently, over many years), these brave souls were able to identify detailed temporal patterns in the movements of various celestial objects. The moon was observed to go through a series of changes in its perceived shape over repeating intervals of time now known as monthly lunar (from the Latin word for "luna" or "moon") cycles. The sun itself seemed to move to higher or lower points in the daytime sky during hotter or colder periods of the year. Also, at different times of the year, the relative physical positions or

Figure 2-1 – The ancient astronomers had little more than their keen eyesight and stubborn dedication to observe the heavens. However, all over the world groups of these remarkable individuals built crude but highly imaginative tools that allowed them to track the complex movements of celestial objects with a degree of accuracy that modern science, with all its complex technologies, can barely match. (Image credit: Wikipedia Commons/public domain)

patterns displayed by the stars in the sky (i.e., the different *constellations*) changed in a systematic and predictable manner. All of these complex changes allowed the early astronomers to develop detailed means (e.g., calendars) to predict the changes of the seasons. This work also had enormous importance for many other human endeavors such as allowing the newly developing agricultural societies to determine the most optimal planting and harvesting times for crops, assisting ship captains in accurately navigating the high seas, plus providing a framework for the controversial science of *Astrology*. The ancient tradition (probably started by shepherds to pass the time while herding livestock at night) of connecting the dots between different stars in the heavens to form constellations representing specific objects (e.g., the *Big Dipper*) or mythological persons (e.g., *Orion, the Hunter*) not only provided "star maps" that allowed people to keep from getting lost at night, it also led to the questionable practice of using the positions of the stars to predict the future behaviors of humans.

From the days of our cave-dwelling ancestors to just a few hundred years ago, the obvious perception that the earth seemed to stand still while the stars, moon, and other objects in the sky moved slowly from one horizon to the other (east to west) on a daily basis, convinced virtually everyone that the earth was the center of the universe and that everything in the sky revolved around us. In fact, one of the more popular views of the early astronomers was that the stars were actually small points of light placed (pasted?) on the inner surface of a thin sphere (actually thought by some to be made of crystal) that surrounded the earth (**Figure 2-2**). When the sphere rotated, the attached stars moved with it. However, one sphere was not enough to explain the movement of all the objects in the sky. On any given night, for example, the moon seemed to move at a pace that closely, but not exactly, matched the east to west motion of the stars. However, from night to night, not only did the moon seem to gradually change shape, its position against the background stars showed an obvious change. Since the moon moved across the sky in a pattern that was distinctly different from that of the stars, it was assumed that it was

attached to the inside of a second sphere that rotated independently from the sphere containing the stars. Furthermore, to explain the movement of the sun, which moved differently from both the moon and the stars (when they could be seen, such as just before sunrise or just after sunset) the astronomers had to propose the existence of a third sphere. Things really got complicated, however, when the astronomers noted that there existed five additional stars that, while sharing the same nightly east to west motion with the moon and other stars, each exhibited an additional extremely slow but complicated pattern of movements that was very different from that shown by any other object in the night sky. These stellar oddballs (now known as *planets*, derived from the Greek word for "wanderer") would sometimes move very slowly in one direction for a period of days, months, or years, and then slowly change directions, in a complicated zigzag pattern. Each of the five planets showed a distinctly different but repeatable pattern of complicated movement (**Figure 2-3**). To explain the strange movements of the planets, the early astronomers had to propose the existence of a whole series of additional spheres, each with one of the planets attached to its inner side. The idea

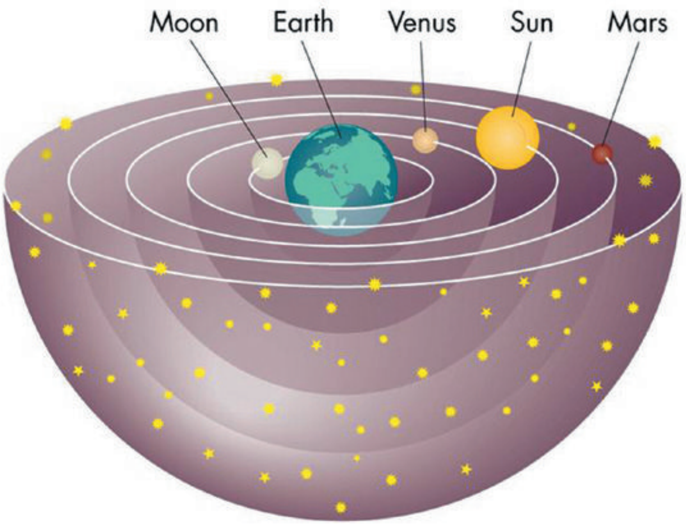


Figure 2-2 - Many early astronomers, including Ptolemy, believed the earth was surrounded by a series of rotating crystal spheres which had the different celestial objects attached to the inner surface. (Image reproduced with permission from Thomas Arny & Stephen Schneider, *Explorations: An Introduction to Astronomy*, 6th ed., Columbus, OH: McGraw-Hill, 2010).

Figure 2-3 – The five so-called "*wandering stars*" (aka "planets") each exhibit very slow irregular motions in the sky that are quite different from the much faster nightly east to west motion exhibited by all other celestial objects. This time-lapsed photograph of the movement of Mars shows that it exhibits a very slow "loop-the-loop" type of motion. This erratic slow motion by the planets is due to the interaction of each planet's own orbit around the sun in relation to earth's orbit. (Image credit: NASA/ Tunc Tezel)

of crystal spheres surrounding the earth was a long held belief. It started in the 2nd century after Christ with the ideas of a Greek astronomer named Ptolemy and stayed in vogue through a whole series of upgrades involving increasing complexity (more and more spheres) until the middle of the 16th century.

One of the basic rules that governs the work of scientists is that, whenever competing theories are proposed that are equally effective at explaining how something works, the simpler theory should be given priority over any that are more complicated (this rule is known in scientific circles as *Occam's Razor*). Having to continually come up with more and more surrounding crystal spheres to explain the movements of stars and other celestial objects was, therefore, finally rejected by a few early astronomers. It is interesting to note that, as far back as around 200 B.C. (before Christ), a Greek philosopher named Aristarchus had already proposed the radical idea of a sun-centered universe. However, Aristarchus' ideas were totally rejected and ignored by his peers at the time. Approximately 1,800 years later, in 1543, a Polish astronomer named Nicholas Copernicus finally succeeded in launching this same radical theory by publishing it in a book. For much of his adult life, Copernicus had believed that the sun, rather than the earth, was the center of the universe. Rather than the sun, moon, and stars all rotating around the earth, the earth, along with the moon (which does rotate around the earth) and the planets, rotate around the sun. Copernicus was well aware that the Catholic Church was vehemently opposed to this idea. For many years, the official religious doctrine of the Church had dictated that man, and the earth on which he lived, being created by God, had to be the center of the universe. Therefore, although Copernicus firmly believed his sun-centered theory of the solar system and had even written a book presenting the idea, he was reluctant to make his ideas public for fear that he might be subjected to severe scorn from the church authorities. However, on his deathbed, Copernicus finally gave into the pressures of his close friends and gave his consent to have his book manuscript published. As a result of his "heretical" beliefs, the Church refused him the last rites of the church and had his body buried in an unmarked grave. In 2010, the church finally reversed its decision and had his body exhumed and reburied with all the rites of the church and as a National Hero of Poland. However, the wrath of the Church against this radical new sun-centered idea was, unfortunately, again taken a big step forward a few years later when, in 1584, an Italian named Giordano Bruno strongly put forward, in both his writings and public statements, the same idea that the sun, rather than the earth, was the center of the universe. While the charges brought against Bruno by the church included a long list of other offending blasphemous activities, writings, and public statements, and not just his opinions on astronomy, he was convicted by the Inquisition, which led to his being burned at the stake in a public courtyard in Rome in 1600.

Thus, for several thousand years, mankind's major tool for studying the celestial objects in the day and night skies were his naked eyes. It is a profound testament to man's tenacity, perseverance, plus ingenuity and intelligence that, repeatedly, in many ancient cultures all over the world, a few individuals were able to learn so much about the field of astronomy. Not only

did they pinpoint the exact movements of various celestial objects so accurately that they were able to develop extremely accurate calendars, they could also predict the future movements of specific celestial objects, e.g., the planets and certain comets, plus predict future lunar and solar eclipses. While, for a very long time, the general population thought that the earth was flat, one ingenious Greek named Eratosthenes was actually able, as early as the 3rd century B.C. to determine that the earth was round and even go so far as to come up with an amazingly accurate estimate of its circumference which missed the mark by only 10% (he estimated the circumference to be closer to 27,500 than its true value of 25,000 miles). With nothing but their eyes, and a few primitive tools, early man accomplished amazing feats in measuring and describing the then known universe, even though, in many cases, their ideas and theories for explaining why and how things happened were incorrect.

Brief History 2 - Telescopes and Spectrometers Open Door to Modern Era of Astronomy

Prior to the invention of the telescope, astronomers had no means to explain what they saw when looking at the night sky. Although the five wandering stars were labeled as planets, the early astronomers did not know whether they might be in any way similar to the earth. As far as the stars were concerned, there was also no way of knowing whether they might be similar to the sun. Some early astronomers probably contrived such ideas in their imaginations but they had no observational data with which they could support such thoughts. In fact, Giordano Bruno, in a further transgression of the religious dogma of his time, also proposed the idea that the stars were actually sun-like objects positioned so far from us that they could only be seen as small pinpoints of light. The idea that other earth-like worlds existed that were populated with creatures similar or dissimilar to man and other animals (or plants) was, however, fairly widespread in the ancient world. Rather than thinking of the wandering planets as being other worlds or homes for living beings, or the stars as being other suns, the question of the "what" and "where" with respect to these other worlds remained very vague concepts, except that a significant number of the educated people at the time believed that such worlds probably existed.

Prior to the 20th century, two major inventions completely changed astronomy from a purely descriptive (i.e., observational) endeavor to a true data-gathering field of science. These inventions allowed astronomers to obtain magnified visual views of the structural features (see what they look like) of different celestial objects plus determine their chemical composition (determine what are they are made of). In 1610, Galileo Galilei, an Italian astronomer, began using a new invention called the "spy glass" (which many historians believe was invented in 1608 by a Dutch optician named Zacharias Janssen) to look at celestial objects in the night sky. This early telescope was a very modest hand held device compared to the gigantic and extremely

powerful versions that would be developed in subsequent years. **Figures 2-4**, **2-5**, **2-6**, and **2-7** depicts the amazing saga of this "**size explosion**" in the development of telescope technology. The first telescope, which Galileo himself built (Figure 2-4a) modeled after Janssen's spy glass, was a little over three feet long, weighed probably no more than three or four pounds, and had a magnification power that was close to 30X (i.e., made the image 30 times larger). A comparable telescope can today be purchased at any hobby store for less than 20 dollars. However, this modest and simple device completely changed the whole history of astronomy. For the first time, man was able to see the detailed shapes and features of different celestial objects. Although the stars did not look any different, they were still tiny points of light, Galileo found that the sky contained a much greater number of these objects than could be seen with the naked eye. When he looked at the moon, he now saw multiple features like small or large depressions on the surface (now known as craters). He also saw what appeared to be mountains, plus darker smooth areas that he thought might be water covered areas similar to the earth's seas or lakes. The moon was no longer seen just as a bright shiny object that systematically changed shape every month. It now seemed to have many distinct features that were almost earth-like. When Galileo looked at some of the "wandering stars", he found that they had unique features that were very different from that of the other stars. **Figure 2-8** shows a photograph taken with a small telescope that shows what Galileo might have observed

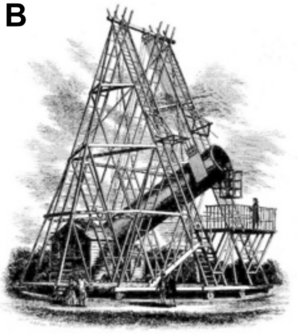
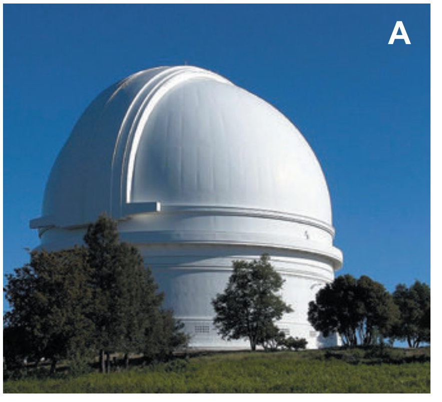


Figure 2-4 - While Galileo's small hand held telescope (**A**) allowed modern astronomy to explode onto the scientific scene, astronomers quickly discovered that larger telescopes would allow them to see much more. Galileo's colleagues quickly began building bigger and more powerful telescopes and by 1789 they (**B**) were beginning to become huge. (Image credits; A – NASA, B – Wikipedia Commons/public domain)



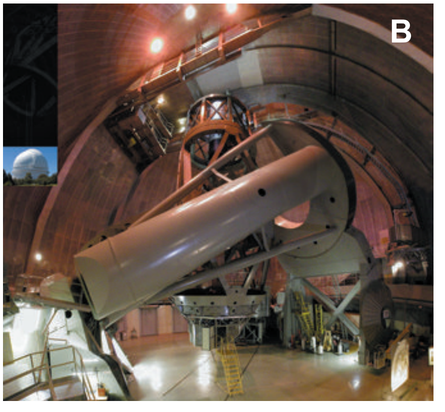


Figure 2-5 - In 1949, the astronomical telescope entered the giant category with the opening of the Mount Palomar Observatory (**A**) on a mountain top outside Pasadena, California (Image credit: Wikipedia Commons). (**B**) shows a photograph of the 200-inch Hale telescope. (Image courtesy of Dr. T.H. Jarrett, IPAC/Caltech)

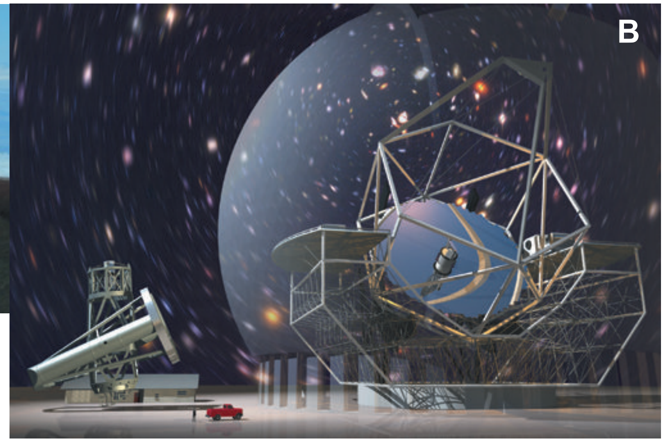


Figure 2-6 - The giant Mt. Palomar telescope was just the beginning. On May 8, 1996, the "twin" Keck telescopes (**A**) were dedicated in a ceremony in Hawaii. The Keck telescopes represented a major breakthrough not just in size but also in optical resolving power through the use of a new computer-based interferometry technique. (Photo credit: P. Stomski, W.M Keck Observatory, Caltech, University of California) (**B**) contrasts the difference in the size of the Mt. Palomar telescope (lower left corner) with that of one of the twin Keck telescopes. Note the size of the pickup truck sitting between the two telescopes. (Image credit: Artistic rendering, Todd Mason/Caltech).

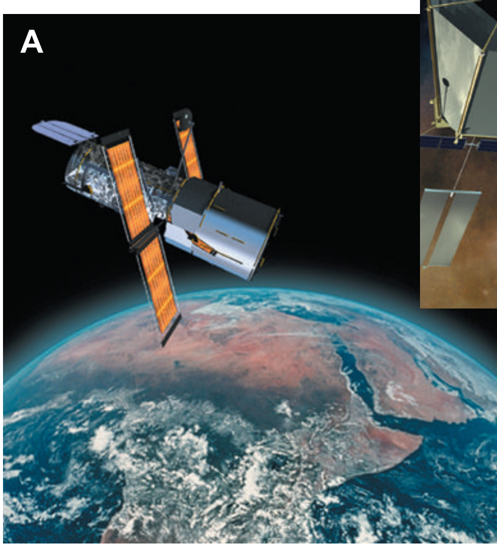


Figure 2-7 - In addition to being dirty and turbulent, earth's atmosphere only allows a small proportion of the total electromagnetic spectrum (light) to reach even the largest ground based telescopes. The advent of the space age signaled the next major breakthrough in astronomy. Space telescopes placed in earth orbit could now be used to "see" at other parts of the electromagnetic spectrum and not just the visible light region. Engineers developed special space telescopes that could see in the infrared, x-ray, microwave, and other parts of the spectrum. These telescopes could see far more and much further into the vast universe than even the best ground based instruments (Palomar, Keck telescopes). The "old man" of this new space based telescope breed is (**A**) the Hubble Space telescope. It has now been working tirelessly in space for 20+ years. While it can see far more than any ground based instruments, it is only about the size of a school bus! In later chapters, the author will describe how future versions (**B**) of these "mighty mouse" space telescopes will allow us to directly view earth-like worlds circling other stars. (Image credits: NASA)

Figure 2-8 - While small, Galileo's first telescope was powerful enough to allow him to view the planet Jupiter and its four largest moons (small white dots) circling around it. This photograph by an amateur astronomer shows what Galileo might have seen when he looked at Jupiter with his telescope. (Image credit: Jan Sandberg/Wikipedia Commons)

through one of his small handheld telescopes when he pointed it at the "wandering star" he and his colleagues called *Jupiter*. This planet was found to have a slightly flattened oval shape and had what appeared to be four small star-like objects that seemed to be circling it. Today, we know that these small circling objects are the four largest of Jupiter's 63 moons that have so far been discovered. These four moons (which are named *Io*, *Europa, Ganymede,* and *Callisto*) are collectively called the Galilean moons of Jupiter in honor of the man who discovered them (**Figure 2-9**). As we will see later, one of these moons, i.e., *Europa*, is now believed to possibly house saltwater oceans below its ice-covered surface that could support some primitive forms of single cell or even multi-cellular life. Galileo also pointed his telescope at the wandering star named *Venus*, which next to the moon, is the brightest object in the night sky. Rather than being a pinpoint of light, like other stars, Venus was found to be a bright round object that goes through, over a period of several months, a series of shape changes or phases very similar to that exhibited by earth's own moon. Thus, in a very short time, Galileo obtained convincing evidence that at least some of the five wandering stars were very much planet-like in the sense of being round worlds not unlike the earth. Based on his telescopic observations, Galileo quickly confirmed for himself (although he had long supported the theory) that Nicholas Copernicus and Giordano Bruno were right - the sun was indeed the center of the universe, and the earth and other planets did indeed appear to be circling (orbiting) around it.

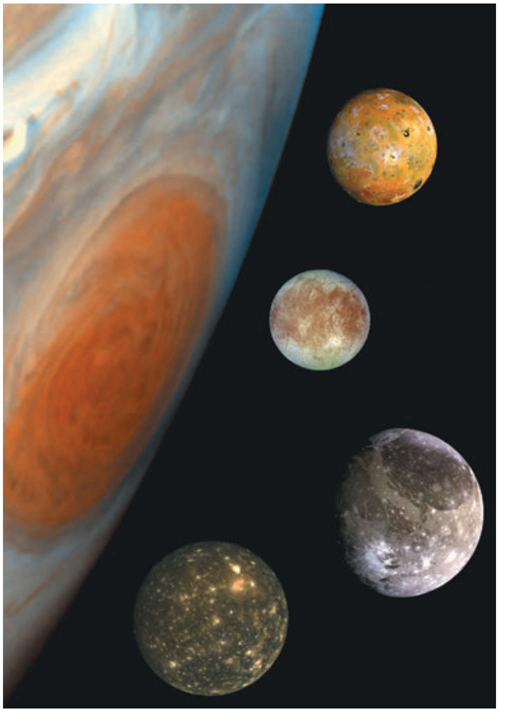


Figure 2-9 - Special NASA photographic display of the four largest of Jupiter's moons alongside the planet Jupiter. Shown from top to bottom are Io, Europa, Ganymede, and Callisto. (Image credit: NASA)

Unfortunately, like his predecessors, Galileo

also ran into conflict with the Catholic Church. The Church put Galileo on trial and found him guilty of heresy for promoting this sun-centered theory. Galileo was ordered to recant his ideas. He refused and, as punishment, was initially sent to prison but later had his sentence commuted to house arrest at his home for the remaining 9 years of his life (he was 69 years old at the time of the trial). In 1979, Pope John Paul II formally suggested that the Catholic Church should consider reversing the heresy conviction that had been imposed on Galileo 346 years earlier. Unfortunately, it was not until 1992 that the church finally reversed Galileo's conviction. As we will see in chapter 3, this same Pope also publicly stated, in 1996, that Charles Darwin's theory of evolution is not in conflict with official Church doctrine. And just recently, in November 2009, the Catholic Church sponsored a special 5-day conference at the Vatican in Rome to consider the possibility of extraterrestrial life in the universe. A group of 30 distinguished scientists and leading theologians came to the unanimous conclusion that not only is such life very likely but its existence does not contradict the Bible.

Now that astronomy had a tool for looking at celestial objects and studying their physical features (at least planets, if not yet stars), the next obvious question was to try to find out what the different objects were made of. As late as the middle of the 19th century, scientists still firmly believed that, even though we could look at celestial objects through telescopes and get information about their physical features, the fact that we would likely never be able to physically visit them meant that we would never have any means of finding out what they are made of (i.e., their chemical composition). However, well before the end of the 19th century, this problem was also solved. In 1863, William Huggins became the first astronomer to begin using the newly discovered technique of ***spectroscopy*** to examine the chemical composition of stars. Light which is visible to the naked eye is made up of a multitude of different colors. If you pass light through a glass or crystal prism, you will see the light spread out in a series of different colors (**Figure 2-10a**). A similar effect occurs when, following a rain shower, sunlight passes through water droplets in the sky to produce a rainbow. However, not all light is visible to the human eye. The human eye is only sensitive to a very narrow portion of what scientists call the total ***electromagnetic spectrum*** (**Figure 2-10b**). All light (i.e., electromagnetic radiation), whether visible to the eye or not, consists of a mixture of different frequencies (colors) that have different wavelengths (some shorter and some longer).

Spectroscopy is a technique that involves collecting light through a telescope from some celestial body and sending it through a special apparatus (similar to a prism) that spreads the light into a multi-colored pattern that shows its spectral content. It is well known that different elements (i.e., individual atoms) or molecules (collections of different atoms electrically bound together) will emit light energy of certain frequencies and also either absorb or reflect light at other specific frequencies. Astronomers can carefully examine the spectral pattern of the light collected by their telescopes to determine what colors are present and what colors are absent. The spectral pattern from a specific source of light will look very similar to that of the bar code that you see in a grocery store on produce labels, except that instead of alternating thin and wide bars that

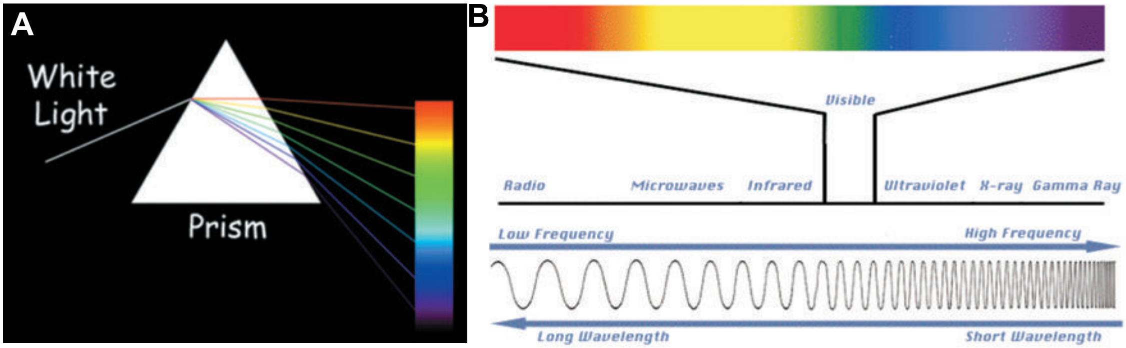


Figure 2-10 - A. When light that is normally visible to our eyes (i.e., so-called "white" light) is sent through a crystal prism (or droplets of rain in clouds), it becomes separated into a collection of different colors ranging from red to blue. (Image credit: NASA) **B** illustrates that the total range of light energies (i.e., the Electromagnetic Spectrum) is far wider than our eyeballs allow us to see. The eye evolved while our ancient ancestors still lived in the oceans. Since much of the total electromagnetic spectrum is blocked by the oceans, our ancestors' eyes evolved specifically to be able to see in the available narrow visible light range. When our ancestors later emerged onto land they still did not need to see beyond the visible range since much of the shorter and longer light wavelengths are also blocked by the atmosphere. Astronomers, however, have found that in order to obtain a more complete, accurate, and detailed view of the different celestial objects in space they need to "see" at these normally invisible parts of the total light spectrum. (Image credit: Unknown)

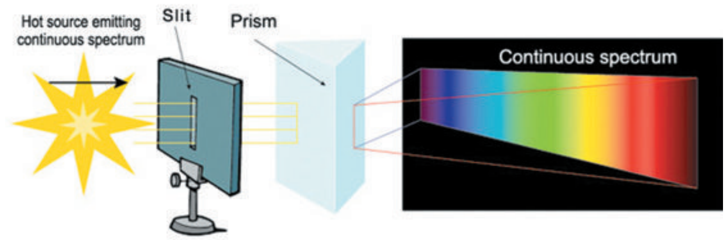
may be light or dark, you will see a series of different colored bands, which are sometimes wide and sometimes narrow in width, intermixed with a series of black bands. *The different colored bands will indicate which frequencies were emitted or reflected, while a black band (no color) will indicate a specific frequency that was absorbed.* For many years, and in many laboratories, scientists have performed extensive studies to determine exactly what spectral patterns are produced by specific kinds of atomic elements (atoms) or molecules (collections of atoms). When astronomers see a particular pattern of spectral lines collected from some celestial body, they can compare this pattern with those collected in the laboratories to confirm what kinds of elements or molecules the celestial object is composed of. **Figure 2-11a-c** shows how different kinds of light spectrums are collected from different celestial objects by astronomers, as well as examples (**Figure 2-11d**) of what the light spectrums of the sun plus five common kinds of atomic elements look like.

Transition to Instrument Assisted Observations reveals a Universe whose Age, Size, and Complexity Boggles the Minds of Scientists and non-Scientists.

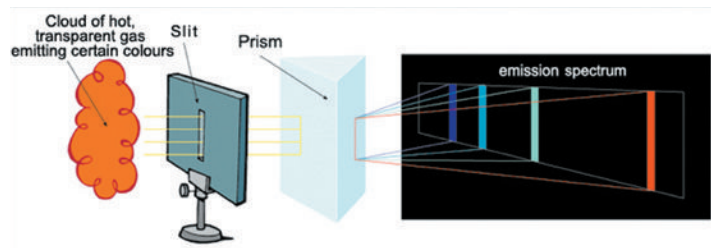
With the invention of telescopes and spectrometers, the extremely long reign of the earth-centered universe was totally and completely replaced by the sun-centered theory. The next step in this new scientific endeavor was to use the new astronomical tools to measure both

Figure 2-11 - Sending light from celestial objects through small crystal prisms will allow scientists to determine what celestial objects are made of in terms of their chemical compositions. Three kinds of chemical spectrums are obtained:

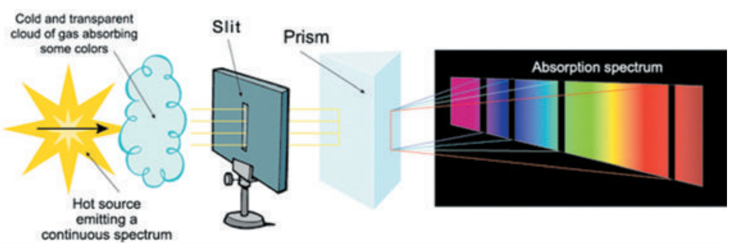
A. When light from an incandescent body (an object that is so hot it glows), like a distant star or galaxy, is sent through the prism, a continuous spectrum consisting of a display of all the colors of the electromagnetic spectrum will occur. The shape of this display will tell astronomers much about the specific physical and chemical properties of the object.



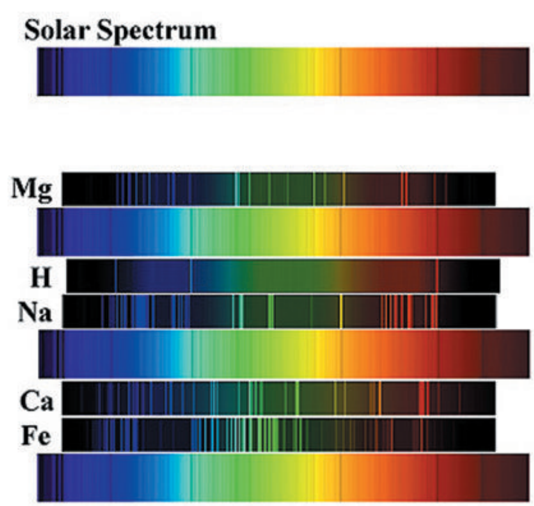
B. Light from other types of hot objects, such as hot interstellar dust/gas clouds, will display another kind of spectrum known as an emission spectrum. These spectrums contain a large number of different kinds of narrow colored bands. The pattern of these bands will tell the scientist what specific chemical ingredients (atomic elements) are present in the cloud that is emitting light energy.



C. A third type of spectrum, known as an absorption spectrum occurs when light from a distant hot object (e.g. a star) passes through a cool or cold interstellar gas or dust cloud. In this case a pattern of black bands will be mixed among the colored bands. The location of the black bands will tell the astronomer what parts of the distant star's light energy is absorbed (i.e., removed) by the chemical elements in the cloud, and thus reveal the chemical composition of the cloud itself.



(Image credits: www..astro-canada.ca ASTROLab du parc national Mont-Maganic)



D. Shows examples of the spectrums of our sun and some common elements (Mg - magnesium; H - hydrogen; Na - sodium; Ca - calcium; Fe - iron). (Image credit: NASA)

Figure 2-12 - Shows a time-lapsed photograph of the Milky Way galaxy as seen in the skies above the Keck Observatory in Hawaii. (Image credit: Kris Koenig)

the extent (size, shape) of the universe as well as determine the detailed structural and chemical makeup of different celestial objects. During the first half of the 20th century, astronomers quickly determined that our universe was much larger than most people could possibly fathom. Prior to the 20th century, most astronomers believed that our sun was part of a collection of stars which was known as the Milky Way galaxy. As far back as 300 B.C., a Greek philosopher named Democritus proposed the idea that the band of white light known as the Milky Way that stretches across the night sky might consist of distant stars (**Figure 2-12**). In 1610, Galileo pointed his new telescope at the Milky Way and confirmed that it did consist of a huge number of dim stars. In 1755, a German astronomer named Immanuel Kant proposed the idea, which is now known to be correct, that the Milky Way consists of a huge number of stars which form a pancake shaped rotating body held together by the force of gravity, not unlike that of the sun and its eight planets, but on a much larger scale. Thus, up until the early part of the 20th century, the Milky Way galaxy was widely thought to encompass the total universe.

However, in the 1920s, an American astronomer named Edwin Hubble (for who the first space telescope was named, see **Figure 2-13**) discovered that the Milky Way was not the only galaxy in the universe. For several years, astronomers had been observing small faint patches of light in their telescopes that they assumed were small clouds of dust that were illuminated by the light from nearby stars. These patches, which they called *nebulae*, were thought to be located inside our galaxy. In 1925, Hubble had

Figure 2-13 - Shows images of the Hubble Space Telescope (**A**) undergoing some repair work by the space shuttle crew (Image credit: ESA/Hubble), and (**B**) as seen drifting slowly away from the space shuttle. (Image credit: NASA)

the use of a newly built telescope (the famous Mt. Wilson observatory in California) that was then the largest and most powerful instrument in the world. When he pointed his telescope at one of these small faint clouds or nebulae, which was located in the Andromeda constellation, he found it contained a few very faint stars that exhibited unusual patterns of changing brightness over time. Such pulsating stars were well known to Hubble, but the ones he had previously seen were all located in our own Milky Way galaxy. These stars, known as *Cepheid Variables*, periodically change back and forth from bright to dim at specific rates that are closely related to their inherent natural brightness. Therefore, by comparing the pulsating rate of one of these stars to how bright it appears to be through the telescope, astronomers can determine how far away the star is. When Hubble did this calculation with the pulsating stars he was seeing in the Andromeda nebula, he was very surprised to find that these stars were much further away than would be possible if they were located in our Milky Way galaxy. It seems that Hubble had found evidence for the existence of other galaxies in space besides our own galaxy. Thus, astronomers had to rename the Andromeda "nebula" as the Andromeda "galaxy". After 1925, the universe suddenly got much larger. The question then became, how much larger?

Figure 2-14 - Shows a photograph taken by the Hubble Space Telescope of the Andromeda galaxy, which is our Milky Way galaxy's nearest neighbor in space. (Image credit: NASA)

From 1925 onward, larger and larger telescopes were built and more and more distant galaxies were discovered. We now know that the Andromeda galaxy (**Figure 2-14**) that Hubble discovered in 1925 is an unbelievable 15 million trillion miles (wow!) away from us and is, along with the Milky Way, part of the so-called *local group* of galaxies. The local group consists of at least 30 galaxies (some astronomers estimate there might be 45 or more), some of which are larger and some smaller than our Milky Way. The Andromeda galaxy is about twice the size (i.e., twice the diameter) of the Milky Way galaxy (**Figure 2-15**). Astronomers estimate that the Milky Way and Andromeda galaxies each contain a total of at least 100 billion individual stars. Earlier, we indicated that the Milky Way galaxy is a huge (definitely, an understatement) collection of stars which are all orbiting around a common center of gravity, not unlike a carrousel (merry-go-round) at an amusement park. In a similar fashion, the local group is a collection of individual galaxies that are also orbiting around a common center of gravity, but on a much larger scale. At the end of the 20th century, with the development of even larger earth based telescopes (which now included special computer based adaptive

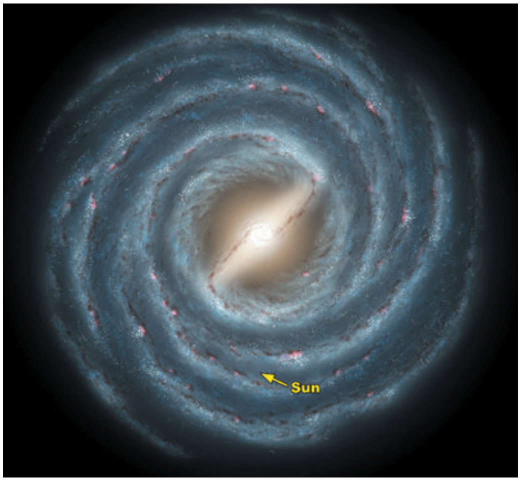


Figure 2-15 - While no human has, so far, managed to get far enough away to get a direct photograph of our Milky Way galaxy, NASA scientists have compiled the images from a large number of separate photographs taken from ground-based as well as space telescopes to get a fairly accurate estimate of what the galaxy would look like. The galaxy is shown as it would appear if viewed from directly above it. Note the location of our sun. (Image credits: NASA/JPL-Caltech/R. Hurt)

optical systems for reducing the interfering effects of the atmosphere) and telescopes placed in space (e.g., the Hubble space telescope), astronomers began to discover even more distant collections of galaxies in the universe. Some of these newly discovered galaxies are even organized into so-called *super clusters* made up of large numbers of individual smaller collections of galaxies similar to our local group. Many astronomers now believe that the universe may contain as many as 100 billion galaxies. As depicted in **Figure 2-16, g**alaxies come in a variety of different

Figure 2-16 - Galaxies come in many sizes and shapes. In many cases the shape we see through the telescope is determined by whether we are viewing the galaxy from above or below or directly from the side (i.e. edge on). Shown are six common types of galaxies as they appear in normal visible light (Image credit: Presben Grosbal/European Southern Observatory)

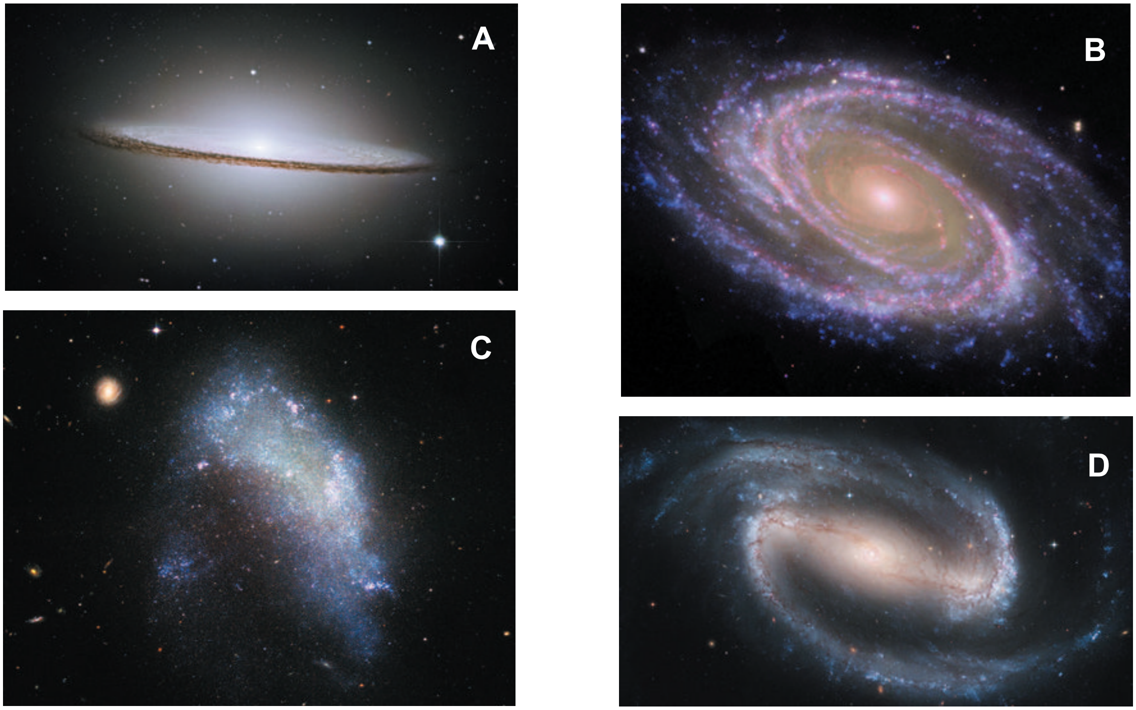


Figure 2-17 - Shows detailed high resolution photographs taken by the Hubble Space Telescope of four typical galaxies. **A.** The so-called Sombrero Galaxy" that got its name because it somewhat resembles the traditional Mexican gentleman's hat. **B.** A common spiral galaxy, similar to the Andromeda and Milky Way galaxies. **C.** A so-called irregular galaxy. **D.** A barred spiral galaxy. (Image credits: NASA's Hubble Space Telescope Collection)

sizes and shapes. **Figure 2-17** shows detailed high resolution photographs of four typical galaxies taken by the Hubble space telescope. Finally, **Figure 2-18** shows a photograph of two galaxies in the act of colliding with each other, which is not all that rare an event in the universe.[1]

Therefore, the invention of the telescope and spectrometer, while opening the door to the rapid growth of knowledge of the universe also brought into sharp focus the inherent limitations of mankind's ability to fathom and comprehend the vast realities of the different celestial objects that were suddenly being thrust upon us by our new measuring instruments. Having grown from childhood on a small planet in a very small corner of a vast universe, we suddenly found that the five sensory systems that nature had provided us were totally inadequate to the task of allowing us to understand the myriad of strange new objects or physical processes that lay

[1]It is interesting to note that our Milky Way galaxy and our closest neighbor in space, the Andromeda galaxy, are moving toward each other at a speed close to 75 miles per second and will collide (merge) three billion years from now. It is extremely unlikely that life-forms (other than astronomers) living in either galaxy, because of their relatively short life spans will notice any changes. The merger itself will also be totally benign since the normal huge distances between stars in both galaxies would make the probability of any two stars actually colliding extremely low. However, the collisions between the dust and gas clouds of the two galaxies would have a positive effect in actually triggering an increased rate of new star and planetary formation in the newly merged super- galaxy.

Figure 2-18 - Shows two galaxies in the act of colliding with each other. (Image credit: NASA, ESA, Hubble Heritage Team)

beyond our own atmosphere. While almost everyone on the planet was totally oblivious to such other worldly matters, those few among us (e.g., the astronomers) who began to look at and study the "heavens" found themselves confronted with observational findings that were totally at odds with anything they had ever experienced before in their lives. Scientists had to develop a new specialized language to describe and explain their new findings. With respect to the age, size, and workings of the different objects of the universe, scientists quickly began using terms or concepts that could not be comprehended by the average person.

For example, the idea that the universe itself was born almost 14 billion years ago (i.e., "bya" for short), and that our earth was formed approximately 4.5 billion years ago (bya), is likely not comprehensible to persons who consider themselves "old" at the ripe old age of 30 something years. Likewise, those of us who might be uncomfortable with the notion that a 3,700 mile trip from New York City to Paris, France would require close to seven hours to complete in a modern jumbo jet, would probably have our minds totally blown if told that traveling the distance to the nearest star (other than our own sun) in the same jumbo jet (at an average speed of 600 miles/hour), if such a thing were possible, would require close to an unbelievable 4.6 ***million*** years to complete (plenty of frequent flyer miles to share with all your relatives, plus everyone else on earth!). And, while it is hard enough to comprehend that the earth (which is far from being the largest planet in our solar system) has a circumference of 25,000 miles, it would be very difficult to fathom the idea that our sun (which is a relatively small star compared to others in the universe) is 2,713,408 miles in circumference, and probably totally unbelievable that the distance from the sun to the most distant planet in our solar system is 2,793,100,000 miles. When it comes to measuring the distances to other objects in the universe, we cannot even use the concept of numbers of miles without getting "writer's cramps". To deal with such huge distances, astronomers have devised a totally different unit of measurement. Instead of miles, they measure distance in ***Light Years***. One light year is the distance that light (which travels at an unbelievable speed of 186,000 miles per second) would be able to cover in a period of one calendar year (364 days,

in earth time).[2] Based on this distance unit, we are now told that the distance from one side of our Milky Way galaxy to the other side (i.e., diameter) is 600,000,000,000,000,000 miles (that folks, is 600 thousand trillion!) or approximately 100,000 light years, and the distance to the furthest galaxies we can see with our most powerful telescopes is 13.2 **billion** light years (please do not ask me to write out this distance in miles). And astronomers now believe that this distance may not be the actual edge of the universe, but only the limitations of our current telescope technology! The reader needs to be forewarned that these "astronomically large" sizes and distances are only the tip of the iceberg to what will be presented, not only later in the present chapter, but also repeatedly throughout the remainder of this book. For example, the author will need to introduce concepts related to the extreme range and complexity of life on earth (from microscopic single cell critters, which are too small to be seen without a microscope, to whales, dinosaurs, giant red wood trees, etc.), to the extremes of temperatures found in the universe (from absolute zero in which everything is frozen solid and nothing, including atoms or molecules, can move, to the hot cores of massive stars), and even the extreme power associated with various celestial and earthly phenomena (e.g., black holes, supernova explosions, asteroid or comet collisions with earth, super volcanoes, etc.).

Therefore, by the middle of the 20th century, due largely to the rapid improvements in telescope and spectroscope technologies, astronomers had achieved a fairly accurate understanding of the nature of the universe. It was the development, beginning in the 1960s, of computers and other space age technologies that truly launched the next major step forward or, actually, "upward" since these technologies quite literally resulted in a "skyrocketing" of our understanding of the universe. All of the different subfields or specialties of the broader science of astronomy (e.g., astrophysics, cosmology, planetary science, and now, "roll the drums", ***ASTROBIOLOGY***) have benefited from these new technologies to the point that all the new information would probably be enough to fill an entire library. In the remainder of this chapter, I will present the latest information on a number of topics in astronomy that are the most closely related to the new discipline of Astrobiology. Again, I will make every attempt to minimize the usage of technical jargon or, when necessary, ask the reader to patiently bear with yet another simplified explanation offered by yours truly. If the reader is fortunate enough to have had some previous exposure to these complex topic areas, they are free to skip these explanations entirely.

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[2]It is very difficult for anyone to make sense of the concept of a light year. That something is able to move at a speed of 186,000 miles per second is unimaginable. The author has found that the following two tidbits of information make this mind boggling concept at least a little easier to swallow. First, the speed of light is so fast that **it is possible for a beam of light to completely circle the earth seven times in one second.** Second, light is so fast (or the sun is so far away) that **it takes the light from the sun eight minutes to travel the 93,000,000 mile distance to earth**. By the way, that closest star we talked about that would take you 4.6 million years to travel to in a jumbo jet, is Alpha Centauri, and is only 4.4 light years away!

"Big Bang" Theory of the Birth of the Universe

Before we can really begin to understand the birth of life in the universe, we must have some understanding of how the universe itself was "born". Shortly after his discovery of the existence of the Andromeda galaxy in 1925, Edwin Hubble and other astronomers began to discover additional galaxies which, along with the Andromeda and Milky Way, are the other members of our local group of galaxies. When he used spectrometry to investigate these galaxies, Hubble made a totally unexpected discovery. Although the spectrograms of the light from the different galaxies showed, as expected, a rainbow like distribution of colors extending from the shorter wavelengths (e.g., blue. violet, ultraviolet) to the longer wavelengths (red, infrared), he noticed that the pattern of the color distribution was shifted slightly more toward the red end of the spectrum for all of the galaxies, which made them slightly redder than normal. This consistent ***red shift*** that Hubble found is associated with a physical phenomenon known as the ***Doppler Effect***. **Figure 2-19** depicts what happens to a galaxy's light spectrum when it is stationary as opposed to either moving away from or towards an observer. As shown in the top image of Figure 2-19, if the galaxies were actually stationary in relation to the earth (which was what Hubble had expected to find) the individual colors of their light spectrums should be equally distributed from the blue to the red end of the spectrum and they would blend together and appear through the telescope as white. If, however, *as Hubble actually observed*, the galaxies were moving away from the earth (as shown in the middle drawing of Figure 2-19), their physical motions would now be in the opposite direction (away from the observer) from that of their light waves (which would be moving toward the observer). This would spread the light waves further apart and make the wavelengths slightly longer which would make the galaxies appear slightly redder. If the galaxies had been moving in the direction of the earth (which they were not, with, of course, the exception of the Andromeda galaxy), both the galaxies

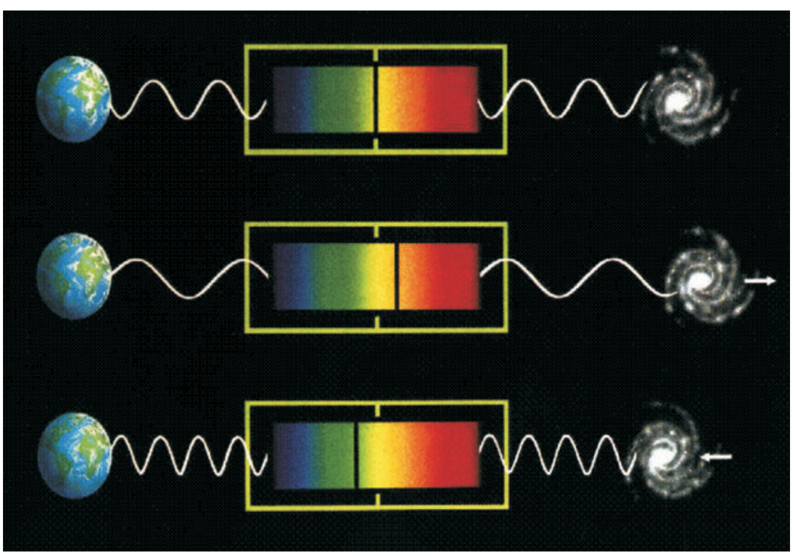

Figure 2-19 - Depicts the red shift effect that occurs in the light spectrum of galaxies as they either move away from us or toward us. (Reproduced with permission from N. Henbest & M. Martin, The New Astronomy, Cambridge Univ. Press, 1983)

as well as their light would be moving in the same direction which would make the light wavelengths shorter (closer together) and cause the galaxies to take on a very slight bluish color (Figure 2-19, bottom drawing). Unfortunately, the extreme speed of light (186,000 miles per second) makes the Doppler Effect associated with light incredibly small and only detectable with extremely sensitive spectrographic measuring instruments. So, in reality, Hubble probably did not personally "see" any increased reddening of the galaxies as they moved away from the earth, but his measurement tools did.

However, since the Doppler Effect also occurs with sounds, the reader has probably experienced this effect when listening to moving sound sources. The reason that we can easily perceive the Doppler Effect with sounds is that the much slower speed of sound (1100 ***feet*** per second) makes the effect very easy to hear. When a police car with its siren turned on is moving towards you, the sounds coming from the siren will appear to be higher in pitch or frequency. As the police car passes you and moves away, you quickly start hearing the siren as suddenly lower in pitch. This change in the pitch of the siren is due to the fact that, when the police car approaches you, both the car and the sounds from the siren are moving in the same direction (towards you) which causes the sound waves to "bunch up" or get closer together and appear to be higher in pitch. As the police car passes you, the sounds from the siren continue to move toward you, while the car is now moving away. This causes the sound waves to become further apart and appear lower in pitch.

After discovering the galactic red shift phenomenon, Hubble compared the more distant members of our local group of galaxies to those that are located closer and made an even more startling discovery. Those galaxies that were located further away exhibited greater degrees of red shift in their spectrums than did those that were closer. This indicated that, not only were all of the galaxies moving away from the earth, but the further away they were, the faster they were moving. This discovery that the universe appears to be expanding suggested that at some time in the remote past, all of the galaxies would have had to be closer together than they are today. The idea of an "expanding" universe was controversial when first proposed. A short time after Hubble announced his discovery of the galactic red shift phenomenon, a Belgium Roman Catholic priest named Georges Lemaitre, who was also an astronomer, and a Russian born astronomer (and later naturalized American citizen) named George Gamow independently proposed very similar theories to explain the apparent expansion of the universe discovered by Edwin Hubble. According to this new theory, the universe originated with a sudden and extremely rapid expansion from an unbelievably small, hot, and dense "object" or "entity" of some kind. Unfortunately, while scientists know a great deal about what happened immediately following the initial expansion or what scientists now call the "Big Bang event", they are ***virtually clueless and can only speculate as to what existed or was happening at or before the time of the Big Bang***. All that scientists know is that "**something**" existed prior to the initial expansion of the universe that provided the originating source from which the entire universe was formed. Several scientists have even suggested that this predecessor to the

universe was not yet matter but was still pure energy. Astronomers also believe that, whatever this "something" was, it may have been as small as a common garden pea or possibly even smaller than an atom.[3]

Immediately after the initial Big Bang event, the universe began to rapidly expand and the pure energy (or whatever it was) began changing into physical matter. At this point, the temperature of the new universe was enormously hot, in fact hotter than anyone (even scientists) can imagine. Initially, because of the extreme heat and pressure, all matter consisted of a super thick plasma-like substance. For the next 300,000 years following the Big Bang, the universe continued to rapidly expand and to rapidly cool down. During this initial period, since no stars had yet formed, the universe was totally dark, with no light radiating out. It would not be until the first stars were formed that the initial "dark age" of the universe would end and the first "***light***" would begin to fill the universe. (Of course no eyeballs would yet be present to witness this important event!) In addition, the super hot and dense plasma-like substance that filled the early universe began going through a large number of very complex physical changes during which it began transforming into solid matter. The author will not attempt to describe or explain the nature of this extremely complicated process since I must admit I do not completely understand it. It is so complex and involved that only those scientists who have devoted their entire careers to specializing in the scientific field of *Nuclear* or *Atomic Physics* probably come even close to fully understanding it. The bottom line is that, by the end of this initial 300,000 year period, all of the basic physical components (building blocks) of the atoms, i.e., electrons, protons, and neutrons were finally created and the protons and neutrons were able to join together to begin forming atomic nuclei. After about 380,000 years following the Big Bang, the expansion of the universe finally allowed the temperature and pressure of the new universe to decline to the point that the electrons were finally allowed to begin circling around the atomic nuclei to form the basic primordial matter of the universe, the hydrogen and helium atoms. At this point in our history, the universe was filled with equal concentrations (although somewhat rarefied) of hydrogen and helium atoms everywhere. The stage was now set for the next major chapter in the evolution of the universe – the creation of stars, galaxies, planetary systems, and eventually life. However, in order for this to happen, the universe that was now filled with equal amounts or concentrations (densities) of primordial matter everywhere would have to begin breaking up into smaller regions (i.e. gas clouds) that differed with respect to the density or concentration levels of their contents. Before beginning this exciting story, we need to wrap up our description of how the universe was born since, as we will see, the concept of a Big Bang event was "not an easy pill for most scientists to swallow".

[3]Some distinguished scientists, e.g., Steven Hawking, even go so far as to state that this initial "*something*" that preceded the Big Bang was *so small* that it could easily be described as "***nothing***". Dr. Hawking, and a few other scientists have, in a quite serious but at the same time "tongue in cheek" manner, described the Big Bang as involving an event in which ***everything that now exists in the universe originated from NOTHING!!***

Not unexpectedly, Gamow's and Lemaitre's theory of the origin of the universe did not go unchallenged for long. In 1948, a British astronomer named Fred Hoyle challenged the idea that the universe was expanding. Rather than expanding, Hoyle argued that the universe was not moving at all. According to Hoyle's view, the universe had always existed in a steady state condition and, in fact, was continually creating new matter to replace old matter that was being lost over time due to the normal birth and death of stars. It is ironical that Hoyle who was far and away the most vocal critic of the expanding universe idea was the person who actually came up with the label by which the phenomenon is now known. In a 1949 public radio broadcast in England, Hoyle jokingly referred to Gamow's and Lemaitre's ideas as the "Big Bang Theory". Although the expansion idea proposed by Lemaitre and Gamow was not an "explosion" in the usual sense of exploding bombs, but rather a more "peaceful" but extremely rapid expansion of space and all its physical contents from an incredibly hot and small (and compact) beginning, the term was quickly adopted by the news media and is the term scientists use today to describe this phenomenon.

In spite of the Big Bang theory being an extremely difficult concept for scientists and everyday citizens alike to understand or fathom, a large amount of supporting evidence for this theory has been obtained since the early 1960s. For purposes of the present book, I will not describe this supporting evidence, but simply state that most experts (astronomers, physicists, and astrophysicists) today believe the essentials of the theory (i.e., the basic theory itself, although perhaps not all of its many minute details) is very likely correct. The idea that every piece of matter that we know exists today in the universe most likely originated from an unbelievably "*small extremely compact hot ball of something*" is, for the author at least, very difficult to accept. However, as we will discuss later in the present chapter, astronomers do know of phenomena in the universe which may make this difficult concept easier to comprehend. For example, we know that there is a tremendously huge amount of empty space not only between the objects in the universe (galaxies, stars, planets, etc.) but also between the electrons and the nuclei of individual atoms.[4] In the next section of this chapter, I will describe a special type of stellar object known as a *neutron star* which is the leftover remnants from supernova explosions of massive (giant or super-giant) stars. When a massive star runs out of fuel to burn in its core, it will quickly collapse onto its own core. During this collapse, the extreme pressure (due to the star's weight) pushing down on the core will cause all of the star's electrons and protons to be squeezed together and converted into neutrons and then be packed together with other neutrons to form a small ball of extremely dense matter made up entirely of neutrons (hence,

[4]Normal atoms have a tremendous amount of empty space between the nucleus (which contains protons and neutrons) and the surrounding clouds of circling electrons. The electrons, in addition to being approximately 1800 times less massive than the protons and neutrons, are also typically positioned at relatively large distances from the atom's nucleus. If the protons and neutrons that atomic nuclei are made of were considered to be about the same size as the small glass marbles that children play with and the nucleus was placed on the floor of a large football stadium (e.g., the New Orleans Superdome) at the center of the 50 yard line, the most distant electron from the nucleus, i.e., in the outer electron shell, would be somewhere close to the ceiling of the building.

the label "neutron star"). While the original star, before the supernova, might have been 80 million or more miles in diameter, the neutron star may be as small as 10 miles in diameter (or even less). A piece of a neutron star as small as the tip of the reader's little finger might weigh (if we could find a scale on earth strong enough for this) as much as the world's largest navy aircraft carrier (or much more). Thus, the idea that everything we know originated from a pea-sized or smaller primordial universe may not be all that outlandish.

However, the author does take some consolation in knowing that, at the time of his death in 1955, Albert Einstein, who was arguably the greatest physicist and cosmologist (scientists who focus on studying the universe as a whole, i.e., its form, nature, history, etc.) of the 20th century also had difficulties accepting the Big Bang theory, although the large amount of subsequent supporting evidence for the theory probably would have led him to change his mind. It is somewhat ironical that Albert Einstein's original version of his famous Theory of Relativity, that he had spent so much time and energy in developing, actually predicted that the universe was either contracting or expanding. Since Einstein was a firm believer that the universe had to be static, i.e., not moving at all (similar to Fred Hoyle's idea of a "steady state" universe) he decided to revise his theory by adding a special mathematical constant (which he called a "cosmological constant") to his equations to make his theory compatible with his ideas of a static universe. A few years later, after meeting with Edwin Hubble and reviewing Hubble's red shift evidence for an expanding universe, Einstein admitted he was wrong in modifying his theory and that doing so was his "greatest blunder" as a scientist. Basically, as we will continue to see throughout the remainder of the present book, when humans began to shift their mental focus away from everyday concepts and issues (earthly matters) to other worldly issues (space, time, birth and death of stars, origins and evolution of life, etc.), they entered a twilight zone where it was necessary to check "common sense" at the door. The old adage that "reality is stranger than fiction" is probably one of the truest statements ever uttered by child, man, woman, scientist, or even science fiction writers!

Formation of the First Stars and the First Galaxies

Thanks to the small but very powerful Hubble space telescope, astronomers now know that, following the initial Big Bang event, our universe wasted very little time in "getting started". The first stars and the first galaxies were already present by 500 million years after the Big Bang. Apparently, by this time all of the hydrogen and helium atoms had already been fully formed and the entire universe was already filled everywhere with these first primordial atomic elements. And most importantly, all of the hydrogen and helium that initially filled the universe in a homogenous fashion (i.e., with equal densities everywhere) had already had time to begin breaking up into increasingly large numbers of smaller regions (i.e. clouds of gas) which had higher concentrations of hydrogen and helium than other adjacent regions. These "dense"

clouds[5] probably came to number in the billions, if not trillions, with some having a mass equivalent of several million sun-like stars. The gas clouds would then start collapsing (due to gravity) and merging to begin the complex process of creating stars and galaxies.

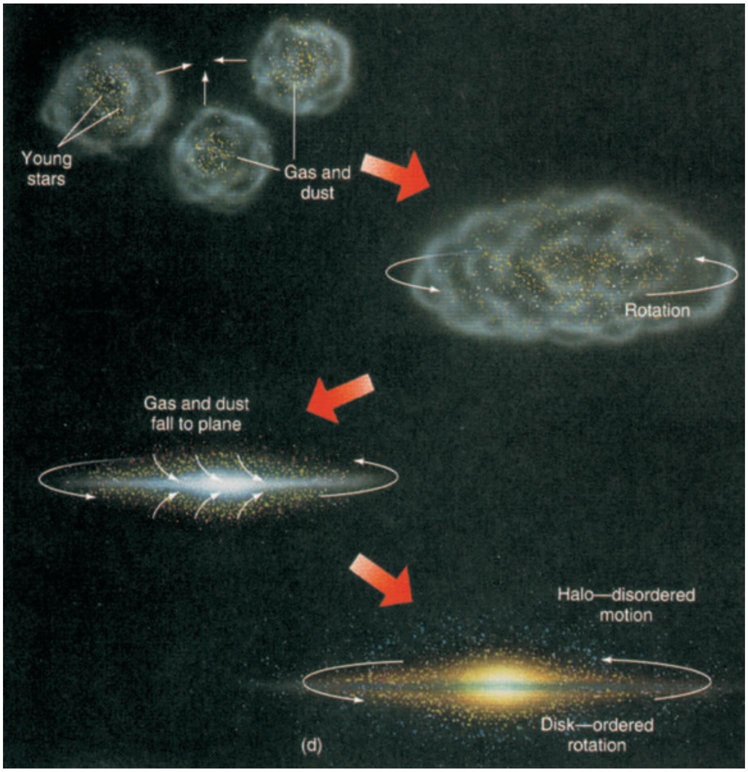

Figure 2-20 - Illustrates how our Milky Way galaxy may have originally formed in the early universe. (Reproduced with permission from E. Chaisson & S. McMillan, Astronomy Today, 3rd Edition, Prentice Hall, 1999):

While astronomers know a great deal about the physical processes that are involved in the formation of stars, they know considerably less about how galaxies are formed. Although many astronomers believe that spiral galaxies similar to our Milky Way galaxy may form simply by the merging of several smaller gas and dust clouds (**Figure 2-20**), there is now new evidence that the galaxy formation process may differ for other types of galaxies (e.g., ellipitical galaxies) and perhaps be even more complex for the formation of the larger super-galaxies. In the next section of this chapter, when the author tells the story of how stars are born and die, I will describe a bizarre celestial object called a "black hole" which is what is left over after huge giant stars die and explode. A black hole is a small extremely compact physical object, possibly only a few miles in diameter, that is so dense that a piece of it as small as a basketball might weigh more than the earth itself. The gravitational field of a black hole is so strong that nothing, not even light, can escape thus making it invisible which is why it is called a "black hole". Whereas astronomers used to believe that black holes only occurred (i.e., were created) when a massive supergiant star reached the end of its life span and exploded in a supernova event, many astronomers now believe that black holes may also have a crucial role in both the earliest stages of the formation of some galaxies as well as the subsequent merging of individual galaxies to form even larger super-

[5]It is important to note, however, that the concentration levels of even the more dense of these gas cloud regions were quite diffuse and may have contained considerably fewer than 100 atoms per cubic centimeter. In marked contrast, the Earth's atmosphere at sea level today has an average density of approximately 2,500 air molecules per cubic centimeter.

galaxies. Galaxies and black holes may actually be created together and grow together in some kind of co-evolutionary process. Although astronomers do not yet fully understand how galaxies and black holes are formed, the fact that most galaxies, including our own Milky Way galaxy, have supermassive black holes at their cores or centers, does strongly suggest the existence of some kind of critical developmental link between these two kinds of celestial objects. It now appears that black holes *may not be just* the horrible "monsters" depicted by science fiction writers in which any and all matter (e.g., planets, unwary astronauts) that venture too close to a black hole get immediately sucked in and totally devoured (destroyed). Thus, black holes appear to possibly be intimately involved in both the creation and the subsequent evolution of galaxies. The story with respect to the creation and evolution of stars and planetary systems is, as we will see next, quite different.

Birth, Life, and Death of Stars and Creation of Heavy Atomic Elements Needed to Build Planets and Life

As described above, once the young universe which was filled with hydrogen and helium gas everywhere began to break up into individual gas clouds of various sizes containing higher concentrations of gas, the process of star formation as well as galaxy formation could begin. Initially, the event that probably caused these gas clouds to collapse was collisions between neighboring gas clouds. Later on, the collapse of some of the gas clouds would likely be triggered by the shock waves produced by nearby supernova explosions of earlier formed giant stars. **Figure 2-21** illustrates how shockwaves from supernova explosions can actually trigger the birth of new stars and planetary systems in nearby gas or dust clouds**.** When these smaller gas clouds began collapsing, they proceeded to become more and more concentrated toward their centers (the technical term is "center of mass", defined as regions or locations where more of the matter is concentrated and has the highest density). Each gas cloud then started rotating or spinning around its growing center of mass. As the speed of rotation slowly increased, the cloud started to lose its round shape and slowly transformed into a flat pancake shaped structure. The center of this spinning disk now contained the newly developing star (i.e., proto-star) while the flat gas envelope surrounding the proto-star, if it contained sufficient amounts of atomic elements heavier than hydrogen or helium, would eventually become the *accretion disc* from which planets would form. **Figure 2-22** shows drawings by artists of such accretion discs, while **Figure 2-23** shows photographs taken by space telescopes (e.g. the Hubble space telescope) of what such discs actually look like. **Figure 2-24** shows an artist's drawing of what the accretion discs shown in Figure 2-23 might look like if an observer could get much closer to them. However, as we will see later in this chapter, if the flat disks surrounding the proto-stars contained only hydrogen and helium gases and no heavier elements, as was typical for the first stars born following the Big Bang, no planets would form.

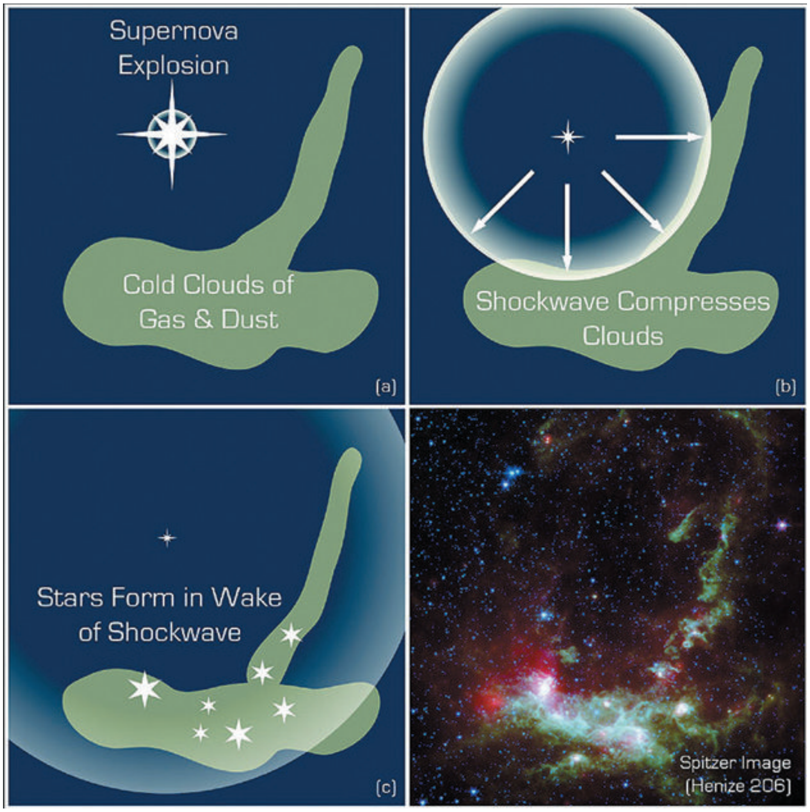

Figure 2-21 – In addition to collisions between adjacent gas clouds, pressure waves from nearby explosions of giant stars were likely the main factors that caused the individual gas clouds in the proto-galaxies to begin collapsing to create new stars. This illustration shows how such a shockwave from a supernova is believed to have caused the formation of new stars in a nearby gas cloud. The photograph in the lower right box shows an actual gas cloud named Henize 206 that became a "new star nursery" as the result of such an explosion. (Image credit: NASA/JPL-Caltech/R. Hurt)

As the gases in the proto-stars continued to collapse and get increasingly dense, the pressure in their *cores* (i.e., centers) continued to increase causing them to become hotter and hotter. Since hydrogen and helium were the primary atomic elements that were created during the Big Bang approximately 13.7 billion years ago the cores of the first proto-stars were composed entirely of hydrogen nuclei plus smaller amounts of helium nuclei.[6] The process by which stars produce energy is nuclear fusion. Nuclear fusion (which was, by way of the invention of the hydrogen bomb, man's most stupid application of his newfound knowledge of nuclear physics) is the process by which the atomic nuclei of lighter elements (e.g., hydrogen) are forced to fuse together to produce the nuclei of heavier elements (helium). While it is relatively easy, and

[6]To understand why the cores of stars contain only atomic nuclei and not complete atoms with circling electrons, the author needs to explain the effects of heat on atoms. The natural tendency of atoms in nature is to either remain isolated from each other or to chemically bond together with other atoms to form molecules. The creation of molecules involves a process by which individual atoms link up (bond) as a result of sharing electrons. As the proto-stars continue to collapse and the temperatures in the cores continue to rise, the intense heat will prevent the atoms from forming molecular bonds with other atoms. In fact, the molecular electron-sharing process is so sensitive to heat that even small amounts of heat may prevent it from occurring (or break any molecule apart into its constituent atoms). Therefore, as the heat and pressure in the collapsing cores of proto-stars become more and more intense, not only are molecules broken apart, but the electrons of individual hydrogen and helium atoms are themselves completely stripped away leaving only the nuclei.

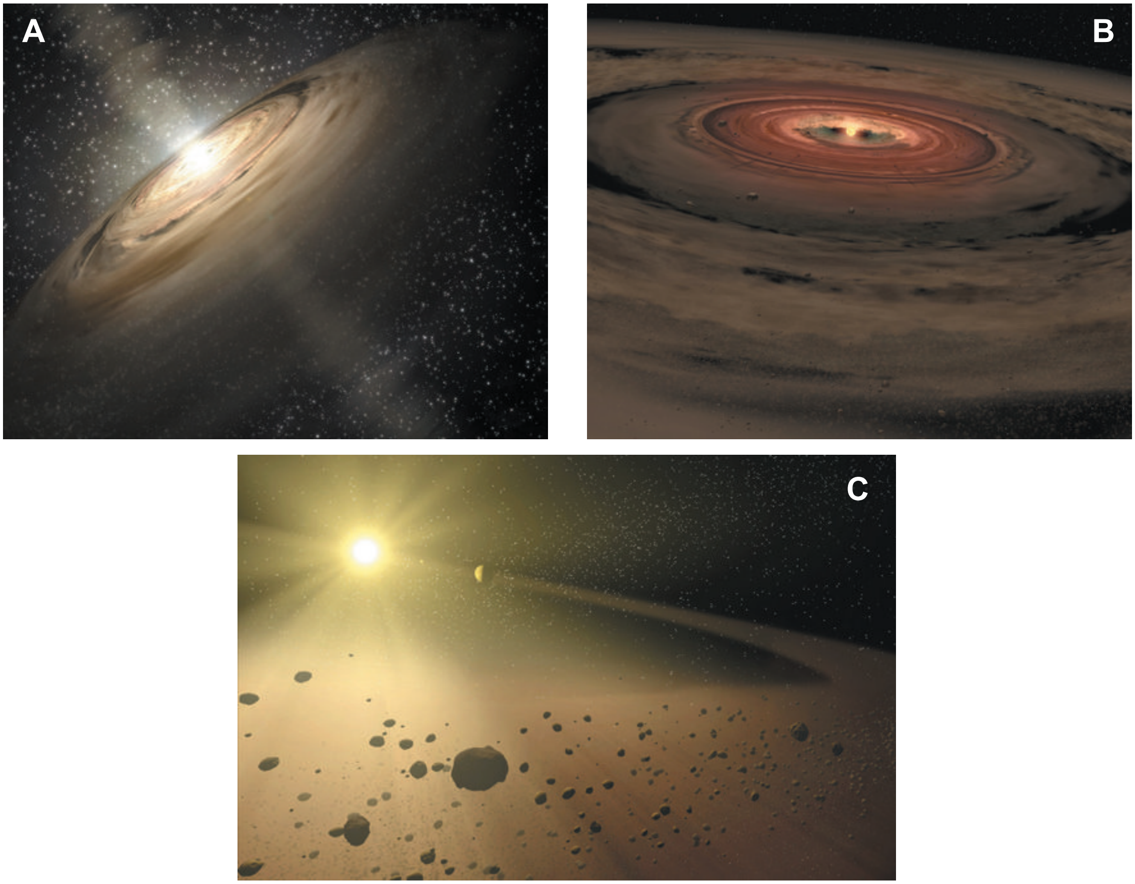

Figure 2-22 - Shows three NASA artists' drawings of what proto-planetary accretion discs might look like the closer you get to them (proceeding inward from **A** to **C**). (Image credits: NASA/JPL-Caltech)

requires little energy, to get atoms to cooperate via sharing their electrons to form molecules, it is extremely difficult to get two hydrogen atoms to allow their nuclei to join together to produce a helium nucleus. This is due to the fact that protons carry a strong positive electrical charge and any two protons would strongly repulse each other.[7] To get such nuclei to fuse together requires a tremendous amount of energy in the form of heat that can only be found in the inner cores of mature stars. Since stars are tremendously huge gas balls, made mostly of hydrogen, their gravitational collapse eventually creates enough pressure and heat to overcome this normally strong repulsive force of the nuclei. When the internal heat of the core reaches

[7]The reader may wonder why protons, since they have the same strong positive electrical charge, would not repulse each other when they are located in the same nucleus of a normal atom. For example, why would the nucleus of a carbon atom that contains 6 protons sitting close together not "explode". The reason is that the 6 neutrons, that are also typically located in the carbon atom nucleus, act to prevent the protons from flying apart. *The neutrons act as the "glue" that holds the nucleus together.*

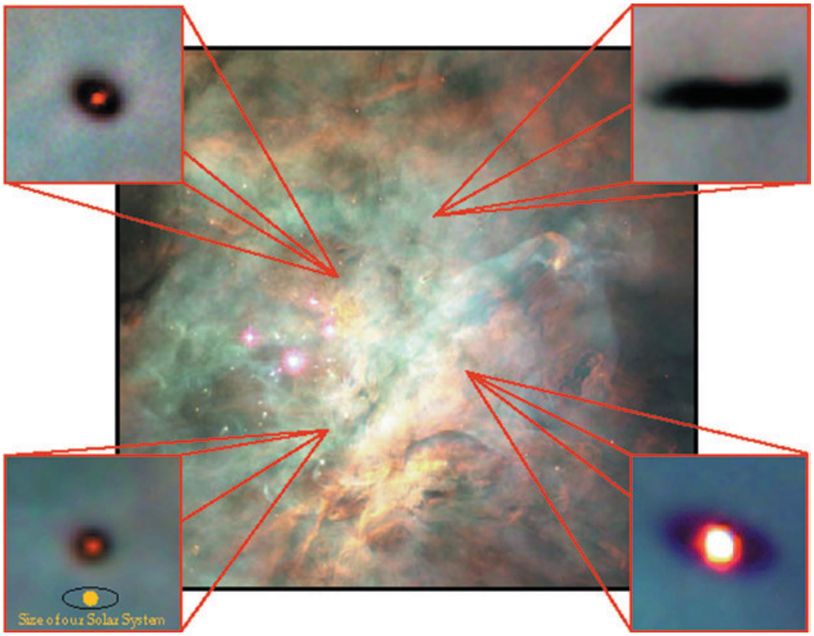

Figure 2-23 - Hubble Space Telescope photographs of actual proto-planetary accretion discs located in the Orion Nebula. The Orion Nebula is one of the many gas and dust clouds in the Milky Way galaxy that is actively giving birth to new stars and planetary systems. The bright colored (white or red) object in the center of each image is the proto-star, while the surrounding dark (black) halo is the accretion dust cloud. Note that the diameter of the accretion disc shown in the lower left photo is approximately equal to that of our own solar system. (Image credits: CR O'Dell, SK Wong, Rice University/NASA Hubble Space telescope)

Figure 2-24 - Shows a NASA artist's excellent drawing of what a typical proto-planetary accretion disc might look like if we were able to get close enough to observe the details of its structure. (Image credit: NASA/JPL-Caltech)

10,000,000 degrees Kelvin[8], the individual hydrogen nuclei begin to crash together with such force that they fuse together to form a helium nucleus containing two protons and two neutrons.

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[8]Astronomers prefer to use the Kelvin scale instead of the Fahrenheit or Celsius scales since it is an absolute scale that begins with the lowest possible temperatures that can exist in the universe, that of 0 degrees Kelvin in which no molecular motion can occur. The Fahrenheit and Celsius scales are more familiar to the general public because they provide quick and easy reference to the common daily phenomena of the freezing and boiling points of water. The freezing point for water is 273 degrees Kelvin, 0 degrees Celsius, and 32 degrees Fahrenheit, while the respective boiling points are 373° K, 100° C, and 212° F. In subsequent sections of the present text, whenever listing temperatures closer to those we earthlings are more accustomed to, however hot or cold, the author will use Fahrenheit and Celsius values.

This fusing of two hydrogen nuclei together to produce a single helium nucleus converts a *very small part of the total matter* contained in the two hydrogen nuclei into a very *large amount of energy*. Incredibly, the total amount of the mass that is lost is only *7/10ths of 1 percent* of the original combined mass of the two hydrogen nuclei. *Each and every day, our own sun converts approximately 400 million tons of hydrogen into helium every second. In this process, 5 million tons of the sun's mass is converted to pure energy every second.* The idea that energy and mass are interchangeable was the brainstorm of the late great Albert Einstein. In the early part of the 20th century, Dr. Einstein presented his famous formula ***E = MC²*** (**E**nergy = **M**ass multiplied by the speed of light or **C** squared) based on his Theory of Relativity. This formula, which has become a very recognizable although frequently misunderstood part of the general public's science vocabulary simply states that a very tiny piece of matter, if totally converted into its alternate energy form would create a huge amount of energy.

The length of time it takes for a full fledged star to completely "form" (i.e., become hot and dense enough that the fusion of hydrogen into helium can begin to occur) out of a collapsing gas cloud depends on the size of the star, with small stars forming more slowly than large stars. A star the size of the sun would take approximately 30 million years to form while smaller stars might require 70 million or more years. Stars larger than the sun would collapse more quickly. Some giant stars might be able to collapse and become dense enough to trigger nuclear fusion in as little as 5 or 10 million years, while super-giant stars might require only a few hundred thousand years to form. Therefore, the first few million years (more or less) in the life span of stars during which they are collapsing from clouds of gas can be considered the *infancy* stage. Once the core of a star becomes hot enough to begin triggering nuclear fusion, the star then graduates from being a proto-star to being a full- fledged *shining* adult star. This *adult* phase of a star's life cycle is referred to by astronomers as the star's M***ain Sequence*** stage. For all stars, the main sequence stage is the period of time in which the star's core contains a sufficient amount of fuel (i.e., hydrogen) to support a constant and steady level of nuclear fusion. This allows the star to maintain a very delicate "balancing act" in which the outward heat-related pressure produced by nuclear fusion in the core continually balances and counteracts the weight of the overlying mass of the star which is constantly trying to make the star collapse in on itself. At the end of the adult or main sequence stage, when the star begins to run out of hydrogen fuel, the star leaves the main sequence and enters its "*old age*" stage. While all stars, regardless of size, require the same starting temperature of 10,000,000° K to jumpstart (technically, the correct terminology is "trigger thermonuclear reactions") the fusion of hydrogen into helium, ***exactly how long a star remains on the main sequence and what happens to it when it leaves the main sequence are both critically determined by its size and mass***. As we will discuss next, a star's specific mass and size determines whether it will be able to produce the heavier atomic elements which are critical to building both planets and life.

Stars come in a large variety of sizes (i.e., diameters), masses (how dense they are in terms of the **amount** of matter they contain), and luminosities (i.e., brightness levels, from dim to very

bright). Stars can range in size from incredibly large "super giants" that are hundreds of times the diameter of our sun to dead stars (i.e., the leftover corpses of stars after they die) that may be only a few miles in diameter or even smaller. Stars can have masses that are 50 or more times greater than our sun or as little as one-tenth the mass of the sun. Any star which has less than one-tenth the mass of the sun simply does not have enough weight and, therefore, cannot produce enough downward pressure on the core to cause it to fire up its thermonuclear engine. Astronomers refer to these non-functional stars as *"brown" dwarfs* since they produce very little light and heat. In recent years astronomers have started to believe that the total number of such failed stars (brown dwarfs) in the universe may be far greater than previously thought. The numbers of brown dwarfs may actually be as great as the numbers of all other kinds of stars combined. Different stars can also be anywhere from several million times brighter than our sun to as much as a million times less bright. **Figure 2-25** shows the typical size range of stars from small *red dwarfs* to huge blue-white *super giants*. (Incidentally, the color of stars tells you how hot they are. Red stars are the least hot, with yellow stars being more hot, and blue-white stars being the hottest) It is important to note that, while the sun may appear to be at the lower end of the size range, it is actually one of the more common types of stars in the universe. On average, for every 100 stars, 90 stars are the same size as the sun or smaller, 9 stars are up to 8 times larger, and the huge stars, the so-called *giant* or *super-giant* stars are in the strict minority. Only 1 out of every 100 stars is greater than 8 times larger than the sun. Early in the history of the universe, there were more giant and super-giant stars than there are today.

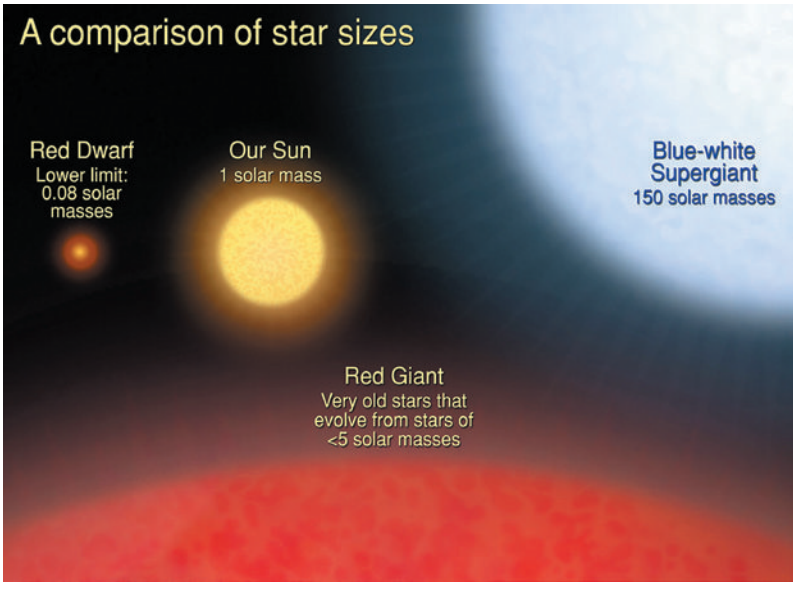

Figure 2-25 - Illustrates the tremendous differences in the sizes of stars that exist in our Milky Way galaxy and presumably in other galaxies as well. (Image Credit: NASA, ESA, A. Field)

As mentioned earlier, for all stars, the key to staying on the main sequence for a long period of time involves maintaining an even balance between the upward force created by nuclear fusion or thermonuclear reactions in the core and the downward force (pressure or weight) exerted by the overlying matter of the star. In order to compensate for this greater related pressure from above, larger stars need to burn their fuel at a faster rate than do smaller stars

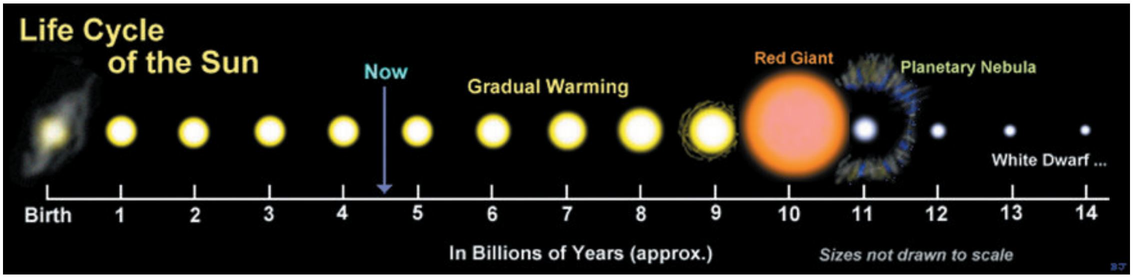

Figure 2-26 - Depicts the normal life cycle of stars that are close to the same size as our sun. (Image credit: Oliver Beatson/ Wikipedia Commons)

that have less weight bearing down on their cores. Smaller stars are, therefore, able to chug away for a much longer time on the main sequence portion of their lives than can larger stars. Our sun, since it is relatively small, has been on the main sequence already for close to 5 billion years, and is likely to keep going for another 5 billion years before it begins to run low on hydrogen fuel and is forced to enter its old age phase (**Figure 2-26)**. While all large stars burn their hydrogen fuel faster than small stars, some very large stars, i.e. the "giants", or even "super-giants", may burn up all their hydrogen fuel and be forced to leave the main sequence in only a few million years or, if they are really "big", in only a few hundred thousand years. As we will see in Chapter 5, astrobiologists now believe that extended times on the main sequence may be critical to allow life enough time to arise and develop. Therefore, smaller stars are more likely to be able to host life friendly conditions than large stars.

However, while it is the smaller stars that may provide sufficient time to allow the development of life, it is the giant stars that allow the creation of all of the atomic elements that are heavier than hydrogen or helium. These stellar "jet setters" who "live fast and die young", are the sources of the heavy elements that are needed to build rocky planets and the complex carbon-based life-forms that scientists believe may inhabit some of them. While both small and large stars experience very similar life styles during their main sequence adulthoods (except for the difference in its length), what happens next during the old-age phase of their lives is drastically different. Smaller stars, like the sun, have a much more "peaceful" old age experience than do the largest stars, but are not able to provide the raw materials (i.e., heavier atomic elements) that will later be needed to allow life to develop. The large stars, in marked contrast, go through a very tumultuous old age and dying experience. While going out literally with a bang, giant stars create a large volume of the heavy elements and even go so far as to spew this material out into the surrounding interstellar spaces so it will be readily accessible for future planetary and life building projects. Prior to beginning, in the next paragraph, a detailed discussion of the differences in the life cycles between low and large mass stars, the reader might want to look at **Figure 2-27** for an excellent illustration of these differences.

After the birth of the universe, many of the first stars that came on the scene were giants by today's standards. Astrophysicists tell us that the largest a star can be without self-destructing

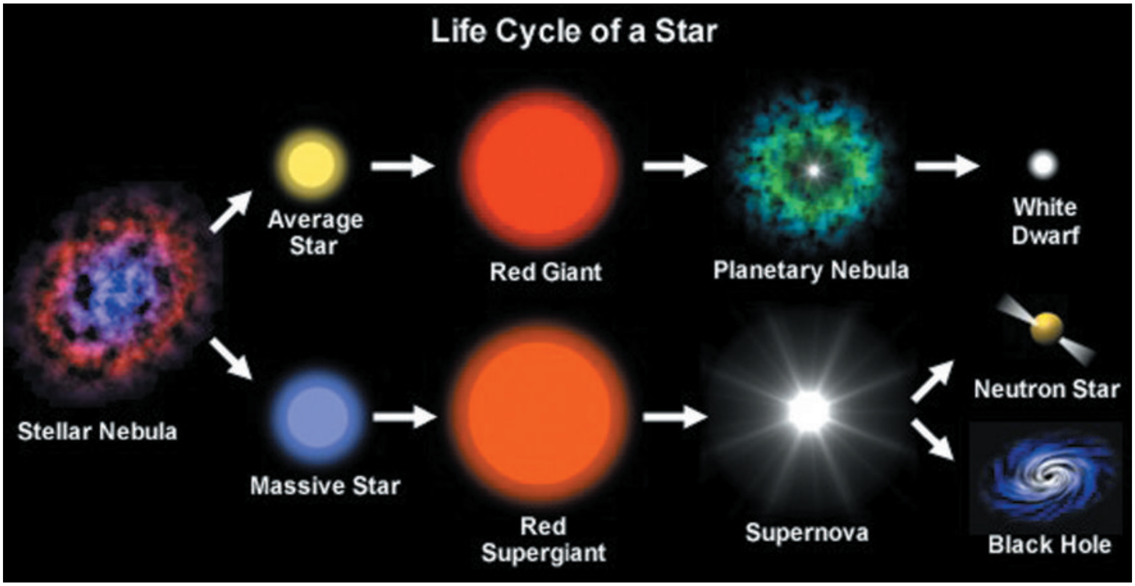

Figure 2-27 - Illustrates the dramatic differences in the life cycles of "average" stars (i.e., those the same size as the sun or smaller) in contrast to that of larger giant and super giant stars. (Image credit: NASA/Seasky.org)

(i.e., the core temperature becoming so high that the outer layers of the star are blown away forever) is approximately 60 times the mass of our own sun. While very few of the large stars formed in the more recent history of the universe reach this mass, stars close to this mass limit were more common in the first few billion years of the universe.[9] Such stellar giants, as described above, spend far less time in the main sequence phase of their lives than do smaller stars. After a period that could be as short as a few million years or less, the star's core begins to run out of hydrogen that is needed as fuel for the ongoing thermonuclear reactions. When this happens, the core starts to cool down. This upsets the delicate balance between the star's tendency to gravitationally collapse in on itself and the counter force generated by nuclear fusion that has, for so long, kept the collapse at bay. As its hydrogen filled "gas tank" begins to approach "empty", the star starts to collapse which increases the temperature of the core. Since hydrogen is now depleted, it is necessary to find a new fuel source. The next heaviest element is helium (with two protons and two neutrons) and is now quite plentiful since, for most of its adult or main sequence life, the star has been busy fusing hydrogen nuclei into helium.

[9]It should be noted that not all stars are single stars. If, in the early stage of proto-star formation, the gas cloud has a mass that is 100 or more times greater than the mass of our sun, it will fragment and result in the formation of a binary or multiple star system, in which the component stars orbit around a common center of mass. Approximately three-fourths of all stars born are part of binary or multiple star systems rather than single star systems. In subsequent chapters, the author will discuss the question of how easily life friendly planetary systems could form around stars that are part of such multiple systems.

However, because helium is a heavier element than hydrogen, it will now require ten times more energy to fuse helium nuclei together to produce heavier elements. It will now require temperatures of 100 million degrees K to accomplish this. When the collapsing core reaches this new temperature, three helium nuclei will begin fusing into one carbon nucleus (which contains 6 protons and 6 neutrons). Some of the helium will also fuse with carbon to produce oxygen nuclei (containing 8 protons and 8 neutrons). As the temperature of the star's core is rising to the new 100,000,000 K level, it also exerts increased pressure on the outer layers of the star which forces the star to rapidly expand in size. The star will rapidly balloon out to become what astronomer's call a *red giant* star. When the helium fuel supply becomes exhausted, the star's core will heat up even more and for a very brief time carbon, neon, and silicon begin fusing to further produce magnesium, and then iron. After iron is produced, the fusion process comes to a grinding halt. The production of iron is the end of the road, since further fusion to create heavier elements would require more energy than the star is now capable of producing.

When a giant star (which is defined as being somewhere between 8 and 15 times more massive than the sun) reaches the stage of producing iron in its core, the core finally runs out of fuel for keeps. The outer layers of the star then immediately collapse into the iron-rich core triggering a gigantic explosion of the star that may momentarily shine more brightly than the entire galaxy. Astronomers refer to this event as a ***supernova*** explosion. All of the recently produced heavier atomic elements (from carbon to iron) are ejected violently into the surrounding interstellar space. The massive heat and pressure generated during the course of the supernova explosion will cause other even heavier atomic elements (all the way up to uranium) to be quickly produced and ejected. The only thing that remains after such supernova explosions, other than the rapidly expanding gas cloud from the explosion itself, is an extremely small and incredibly dense remnant of the star's core called a ***neutron star***. As briefly mentioned earlier in the section on the Big Bang Theory, neutron stars contain only neutrons that are packed so tightly together that a thimble full of the matter from such a "star" would be unimaginably heavy.

If the giant star is even more massive, i.e., is a ***super-giant*** with a mass 15 to 30 times (or more) greater than that of the sun, the supernova explosion will be much more intense (the explosions of the largest stars are so intense they are referred to as "*hypernovas*" by astronomers). In this case, rather than a small extremely massive neutron star being left over as a remnant of the explosion, the exploding star will leave behind one of those very bizarre celestial objects that I alluded to earlier known as ***black holes***. A "black hole" is not a "hole" in the traditional sense of the term, but is similar to neutron stars in being an incredibly dense and massive physical object. Black holes are so much more massive and dense than neutron stars that nothing, not even light, can escape their gravitational clutches. Thus, neutron stars, while extremely massive, will allow light to escape and can be seen. Black holes, while essentially similar to neutron stars but even more massive, will prevent light from escaping and will forever remain invisible, hence the name "black hole".

As mentioned earlier, stars with masses close to that of our sun (or less), do not go through the same dramatic death throes that do their giant and super-giant cousins. When these smaller stars run out of hydrogen fuel and leave the main sequence they will also turn to recruiting new fuel to continue the fusion process. When the hydrogen becomes depleted the core will begin to cool which will allow the outer layers of the star to resume gravitationally compressing the core and raising its temperature. As the core temperature begins to rise the star will begin expanding and the star will become a ***red giant***. It is believed that our sun will turn into such a red giant about 5 billion years from now. At that time, the diameter of this successor to our sun will increase to the point that our earth will actually be swallowed by the outer layers of this new red giant star (**Figure 2-28**). Meanwhile, when the new core temperature reaches 100 million degrees K, helium nuclei will begin to fuse into carbon and oxygen nuclei. When the supply of helium is exhausted it will be the end of the road for our "old sol". No further fusion will occur and the outer layers of the red giant star will be blown away, not by an explosion like that of supernovas, but by a more gentle wind type phenomenon which will expose the core. The core, because of its huge content of leftover heat, will continue to shine for awhile as a ***white dwarf*** star but will eventually lose all its heat and become a cold dark lump of very dense matter. Although stars the size of our sun or smaller do actually produce some heavier elements needed for future development of life, such as carbon, this material will be forever locked away in the interior of the star's corpse, and not accessible to the rest of the universe. The death cycle of sun-like stars never involves explosions severe enough to eject this material into the surrounding interstellar regions. **Figure 2-29** shows a photograph taken by the Hubble Space Telescope of a *planetary nebula* which

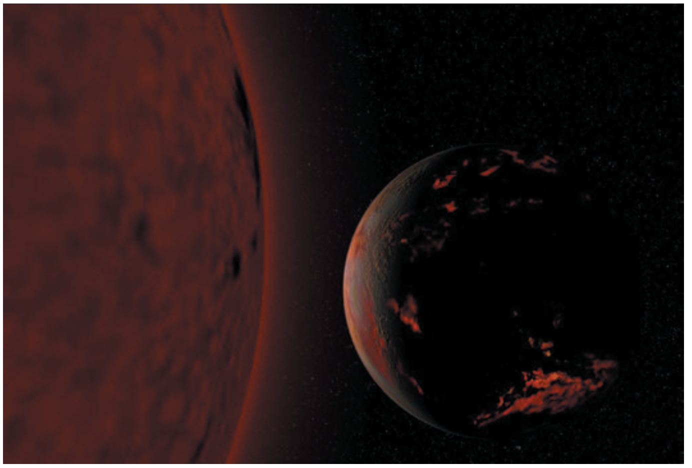

Figure 2-28 - Shows a NASA artist's drawing of what the earth might look like 5 billion years from now when our sun expands into a red giant star. The earth would be extremely hot with much of the surface being in a molten state. No life would be possible. (Image credit: fsgregs/Wikipedia Commons)

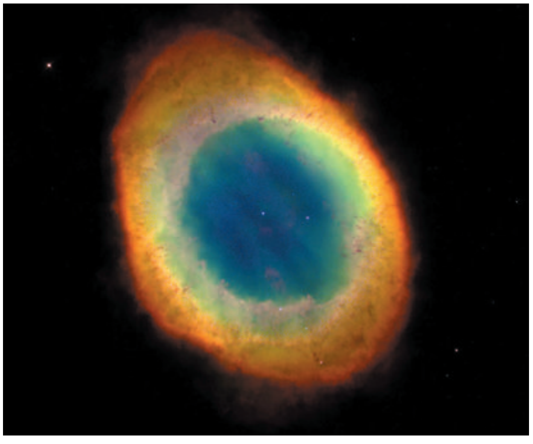

Figure 2-29 - Shows a photograph of a star similar in size to the sun as it goes through its more gentle "death throes" to become what astronomers refer to as a planetary nebula. This descriptive label was apparently chosen because of the similarity of these celestial objects to that of planets. (Image credit: NASA's Hubble Space Telescope Collection)

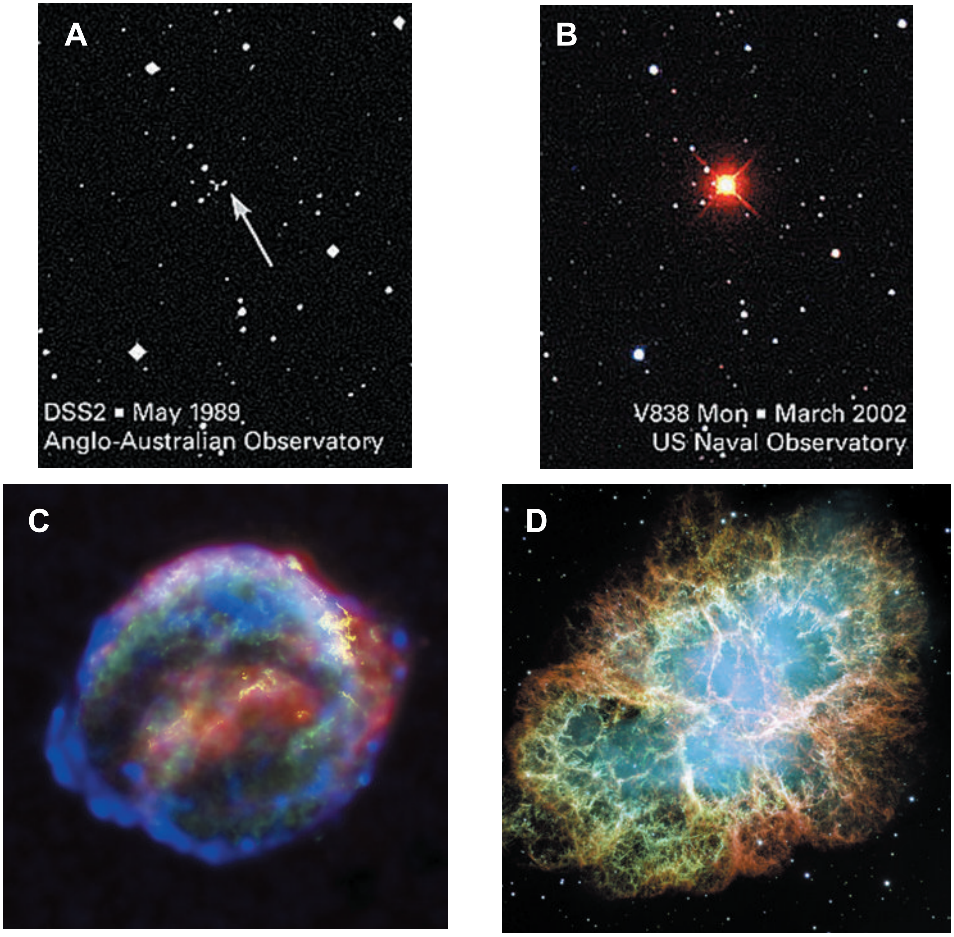

Figure 2-30 - Supernova explosions, while violent and sometimes dangerous to any nearby life-forms, are the source of all the chemical stuff that is needed to build both planets and life. **A** and **B** shows "before" and "after" images of a very distant supernova event. (Image credits: Anglo-Australian and U.S. Naval Observatories). **C** shows a closer supernova as it appeared only 400 years following the explosion (Image credit: NASA), while **D** shows what a supernova looks like many years alter the explosion. This latter supernova (which is now named the "Crab Nebula") was actually viewed and recorded by ancient Chinese and Arab astronomers in the year 1054 and was so bright that it could be easily seen in the daytime sky. (Image credit: NASA/ESA)

is the remains of a recently deceased star that was close to the same size as our sun. Finally, the extreme violent nature of supernova explosions is depicted in **Figure 2-30** by a series of photographs showing supernova events at various stages of their occurrence.

Construction of Planetary Homes for Life

Scientists now believe that most stars will develop a flat disk-like cloud of dust and gas that rotates around the central proto-star embryo, and that perhaps as many as 20 to 50 percent, or possibly even more, of these clouds may eventually develop into planetary systems. While the idea that

planets might form from dust clouds surrounding stars was proposed as far back as the 18th century by the French astronomer Pierre LaPlace, it was not until the 1980s that definitive evidence for such a possibility was obtained when some astronomers developed special computer-assisted adaptive optics in newer telescopes that allowed them to selectively block out or mask the light coming from individual stars so that nearby objects could be seen and photographed. When the mask (which astronomers call a *coronagraph)* is in place, it is possible to see the surrounding gas/dust clouds (**Figure 2-31**) that are illuminated by light from the star. The launching in 2003 of a special space telescope (NASA's ***Spitzer Infrared Space Observatory***) that could "see" and record infrared light provided even more definitive evidence. As we will discuss shortly, the disk-like clouds surrounding stars are hotter than the interstellar regions of space. This elevated cloud temperature is the result of frictional heat produced by gas and dust particles colliding and rubbing against each other as well as heat radiated into the cloud from the collapsing proto-star. The Spitzer Space Telescope is able to photograph the heat-related infrared radiation that such rotating dust clouds are emitting.

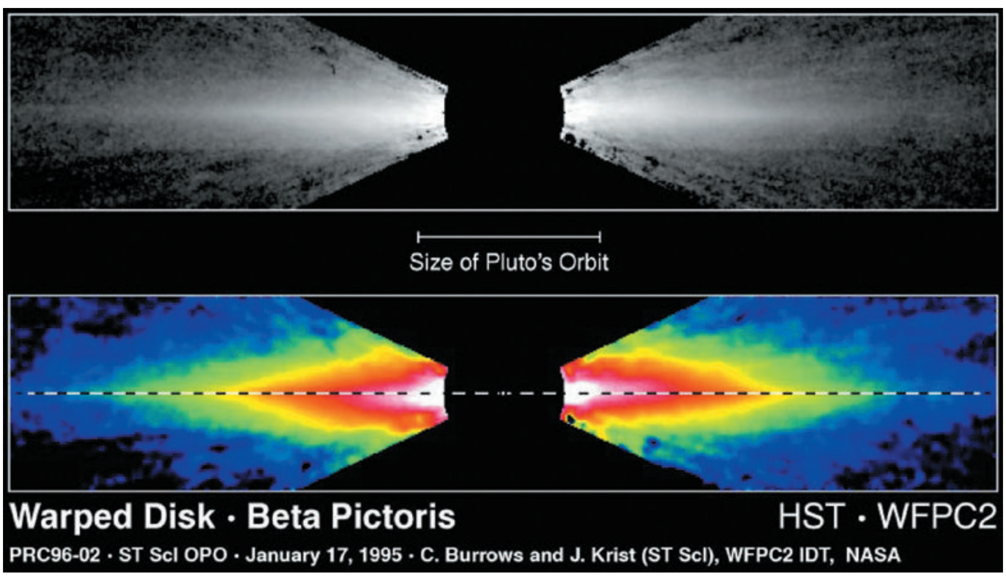

Figure 2-31 - Shows two more views of protoplanetary accretion discs as viewed edge-on (from the side) with the Hubble telescope. The top photograph shows the disc in visible light while the bottom photo shows the temperature gradient of the disc from white hot to cold blue. In both images the light of the proto-star was blocked out by a special mask (seen here as a dark circle in the middle of the discs). (Image credit: C. Burrows & J. Krist/NASA)

The flat gas clouds that revolved around the first generation of the earliest stars[10] created following the Big Bang consisted primarily of hydrogen and a little helium. No heavier elements had yet

[10]For some odd reason, astronomers have traditionally referred to the sequential order, following the Big Bang, of the birth of stars as starting with "third" generation, followed by second, to more recently born first generation stars. Our sun is considered to be a first generation star. To avoid confusion, the author will reverse this classification scheme in the present book. Thus, the first born stars are "first" generation, followed later by the second generation, and then "the new kids on the block", the third generation, which includes our sun.

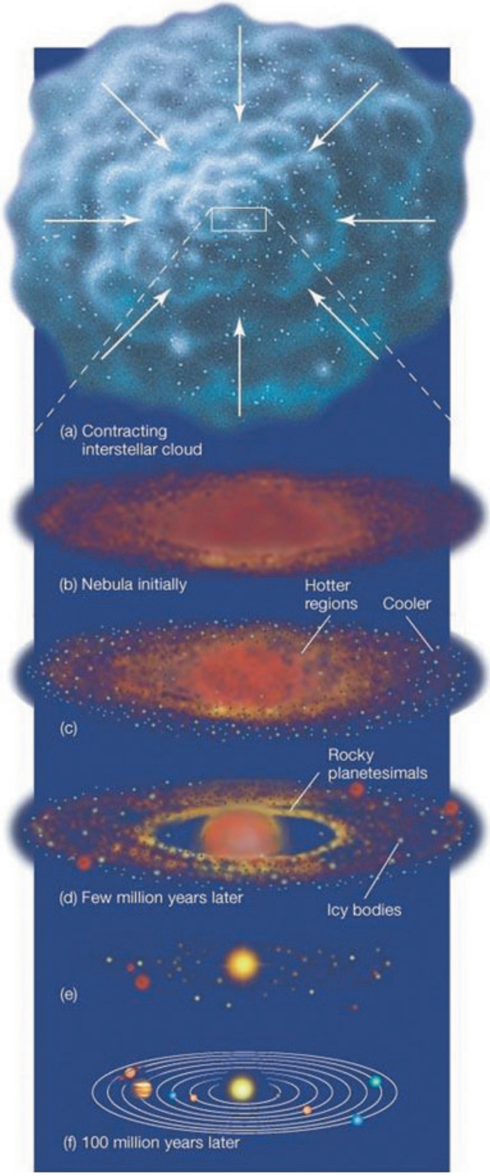

Figure 2-32 - Illustrates the stages in the development of a planetary system: Following a nearby supernova event, the gas/dust cloud (**A**) begins to gravitationally collapse in on itself and, at the same time, begins spinning. As the cloud contracts (**B** and **C**), it starts spinning faster and begins to take on the form or shape of a flat pancake with a bulge in the center (the location of the new proto-star). As the accretion disc spins even faster (**D**), a series of concentric rings of dusk clouds begin to form. These rings will eventually become new planets. More and more of the dust in the spinning rings begins to collide and stick together (**E**) and grow into small particles and then planetesimals ("miniature planets"), and eventually full sized planets. Finally, **F** shows how the final solar system looks like after most of the leftover gas, dust, and debris from the planet formation stage is removed. (Reproduced with permission from E. Chaisson & S. McMillan, Astronomy Today, 3rd Edition, Prentice Hall, 1999)

been created and dispersed into the surrounding interstellar spaces. This prevented the creation of dust particles which are formed from the heavier elements. Since dust particles are the primary building blocks from which at least the solid rocky cores of all planets are formed, planet formation was not possible at this early stage. However, since a large number (larger than today) of the earliest stars were giants or super giants, with very short life spans, the creation of such heavy elements was occurring at a rapid pace. Although perhaps not so much for the second generation, at least by the time the third generation of stars came along, a stockpile of heavier elements was available that could be used for building planets. The author, however, needs to clarify that the magnitude of heavier elements available in the universe is, even today, substantially smaller than the amount of hydrogen and helium. While the amount of heavier elements varies from one interstellar cloud to another, the most that any cloud contains is typically only 2 or 3% of the total mass of the cloud. This, however, appears to be enough to allow the development of rocky planets and carbon-based life, or at least it was once upon a time in our small corner of the universe.

As mentioned earlier, astronomers use the term *accretion discs* to refer to the flat disks containing dust and gas that rotate around newly forming stars. In describing the manner in which these surrounding dust/gas clouds develop into planetary systems, we will focus on the development of the only example for which we have substantial knowledge and that is our own solar system. **Figure 2-32** shows an excellent artist's drawing of the different stages that our solar system is believed

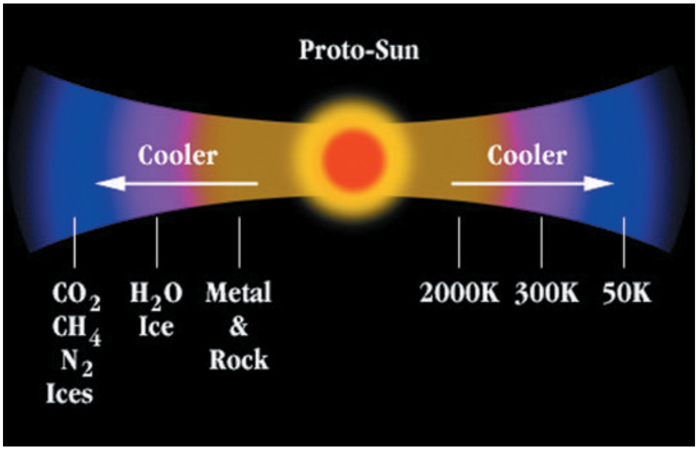

Figure 2-33 - Shows an artist's drawing (edge-on view) of how accretion discs are constructed. The gas and dust contents of the disc become cooler with distance from the star. In the hotter areas adjacent to the protostar, only the less volatile substances like metal and rock are able to condense (change from gas to solids), whereas more volatile substances like water, methane, and ammonia can only condense (i.e. change from gaseous to liquid or icy forms) in the cooler outer parts of the disc. (Image courtesy Dr. Fran Bagenal)

to have gone through in its formation. While most astronomers believe that our solar system may be a good example of the way in which such planetary systems typically develop we will likely, in future years when we are able to examine more and more exoplanetary systems, discover some variations on this planet formation process. As will be described later in the present book, the new adventuresome breed of astronomers known as the ***Planet Hunters*** have already found some evidence that there may be important differences in the way larger gas giant planets similar to Jupiter and Saturn developed in our solar system and how they may develop in some other planetary systems. In our solar system, however, it is thought that the initial accretion disc (**Figure 2-33**) was very wide, possibly extending out as far as 100 times the distance of Pluto, which until very recently, was thought to be our most distant planet. (Pluto was recently demoted from the rank of "planet" - more on this story later) The temperatures in the accretion disc were highest in the regions closer to the developing sun and decreased with distance toward the outer edge of the disc. This is due to two factors. First, the inner parts of the disc are closer to the proto-star and therefore receive more radiated heat than do the outer regions. And, secondly, the inner regions rotate around the star at a faster rate than the outer regions which produces more frictional heat associated with more frequent and energetic collisions between dust particles and gas particles. While the upper and lower portions of the pancake shaped accretion disc contained gas (mostly hydrogen and a little helium), the middle part consisted of a relatively thin layer of dust.[11] Dust in this case does not mean "small particles of dirt", in the traditional sense of the word, but rather small conglomerations of matter (mostly heavier elements) that have condensed from a gaseous to a grain-like solid state. In the regions closer in to the sun, the temperatures in the accretion disc were so great that only non-volatile

[11]The reason the dust ends up in the middle or mid-plane of the surrounding accretion discs is due to the fact that dust is more massive or dense than gas. Whenever, a cloud that contains a homogeneous mixture of both lighter gas and heavier dust begins to spin, the laws of physics dictate that the heavier matter will settle to the most rapidly rotating middle region while the lighter materials will be assigned to the slower moving peripheral region.

(i.e., materials that tend to stay in a solid state as opposed to a gaseous or liquid state) metals (e.g., aluminum, silicon, iron) could form into dust grains. Further out from the sun, at the distances of the gaseous giant planets of Jupiter, Saturn, and beyond, the temperatures were low enough that volatile forms (i.e., elements that tend to remain in a gaseous or liquid state) of matter could exist, so that dust grains in these more distant regions, in addition to containing metals and rocky materials, also contained a large amount of water ice and frozen methane and ammonia gases.

Therefore, the primary factor which determined both the size and the chemical composition of the different planets in our solar system was the large temperature gradient that existed in the accretion disc. The specific chemical composition of the dust grains, which formed the building blocks for the planets, was markedly different between the inner and outer regions of the disc. In the very early stages of planet formation, the dust grains were so small that the only way they could begin to "accrete" (i.e., stick together to form larger grains or particles) was via static electricity. However, stick together they did, until the particles grew into extended fluffy grain-like particles with diameters of 1 millimeter or more. After that, they continued to grow, assisted less and less by electrical forces and more and more by frequent violent collisions which forced them to stick or fuse together, until they eventually reached the 1 to 10 kilometer diameter range. At this point, gravitational forces jumped in to produce a runaway accretion process that led rapidly to the formation of a large number (perhaps numbering in the tens or hundreds of millions) of *planetesimal* (i.e., "small" or "mini" planets) size objects, some of which approached the size of the earth's moon. In the final stage of planet formation, the planetesimal objects began colliding together to produce the present day planets. This last stage was quite violent. The large planetesimals began crashing into each other with such force that extreme amounts of heat were created. The collisions were sufficiently intense to actually melt the colliding objects. **Figure 2-34** shows an artist's drawing of what this extremely hot and violent early stage of formation of the earth might have looked like. The extreme heat produced by the colliding planetesimals, in conjunction with a second major heat source related to the radioactive decay of unstable atoms (to be described later in chapter 4) kept the entire earth in a constant molten state. This semi-liquid condition allowed the heavier materials (e.g., iron and nickel) to sink toward the center of the developing planet and the lighter metals and rocky materials (such as silicates, i.e., rocks made of silicon bonded to oxygen) to rise to the surface. Although

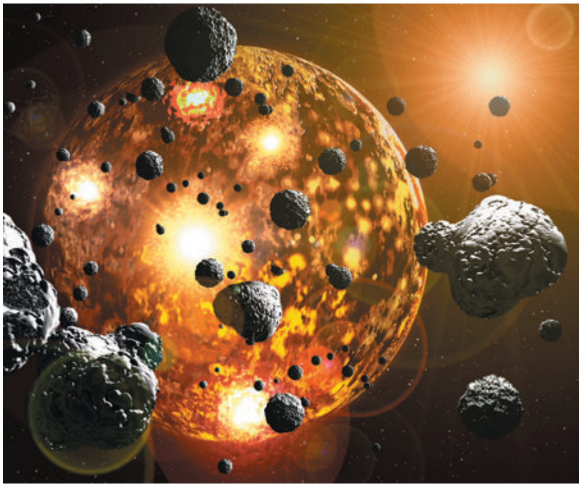

Figure 2-34 - An artist's view of the violent later stages of the earth's accretion when the planet was in an extremely hot molten stage and being continually bombarded by huge rocky materials (planetesimals). (Image courtesy of Julian Baum/Take 27 Ltd.)

less is known about the chemical composition of the cores of the outer planets, it is reasonable to assume that they too are made up of heavier materials, perhaps more rocky-like than metallic (i.e., less iron and nickel)[12]. In contrast to the outer planets, scientists do know a great deal more about the internal composition of the inner planets, and especially the earth. The earth and the other inner planets have central cores made up largely of iron with smaller amounts of nickel. While the innermost part of the Earth's core (i.e., the inner core) consists of a super-hot iron/nickel alloy that is solid because of the extreme pressures of the earth above, the surrounding outer core is made up of molten iron mixed with small amounts of sulfur and oxygen.

Therefore, in the hotter inner portion of the accretion disc, the dust grains containing non-volatile ingredients (iron, aluminum, silicates) came together to form the terrestrial ***rocky*** planets (Mercury, Venus, Earth, and Mars), while in the much colder outer regions the ***gas giant*** planets (Jupiter, Saturn, Uranus, and Neptune) developed from dust grains containing both the non-volatile materials plus a large concentration of additional volatile matter (ices and gases). Since more building materials (rocky materials and metals, plus water ice and ammonia/methane gases) were available in the colder outer regions of the solar system, the gas giant planets were able to develop central cores that were considerably larger and more massive than the cores of the inner terrestrial planets. The cores of the outer planets (Jupiter, Saturn, Uranus, and Neptune) are 10 to 20 times more massive than the cores of the inner planets. In addition, while the smaller inner planets were not large enough to gravitationally attract any of the lighter hydrogen and helium gases from the accretion disc, the more massive outer planets accumulated a very large amount of these materials. Because of the attraction of these lighter gases on top of their large cores, the outer planets became quite massive. Jupiter, in fact is approximately 320 times more massive than earth, with Saturn being 95 times more massive, and Uranus and Neptune 15 and 17 times more massive, respectively. **Figure 2-35** illustrates the tremendous differences in the relative sizes of the different planets in our solar system. The

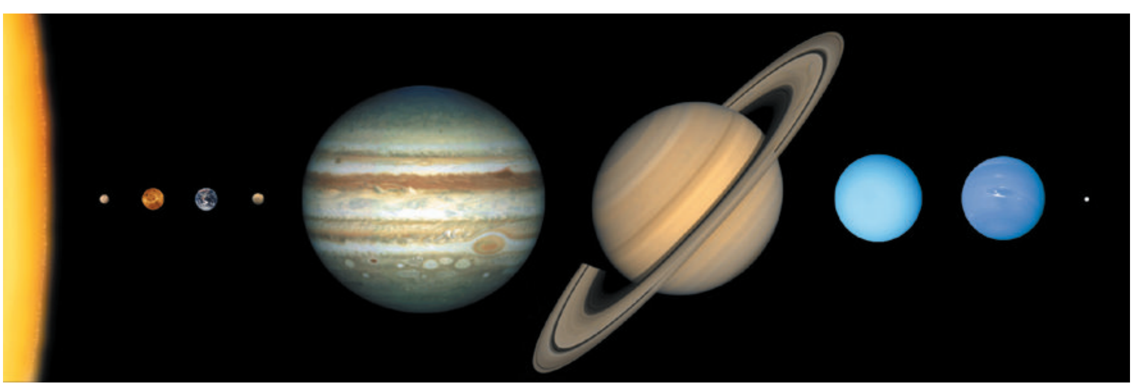

Figure 2-35 - Artist's drawing depicting the relative sizes of the 8 planets (plus Pluto) of our solar system. (Image credit: NASA)

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[12]For some strange reason, most astronomers refer to any atomic elements that are heavier than hydrogen or helium as "metals". Thus, carbon and oxygen, as well as iron, are all metals, according to astronomers. The author finds this confusing and has, accordingly, ignored it for purposes of writing this book.

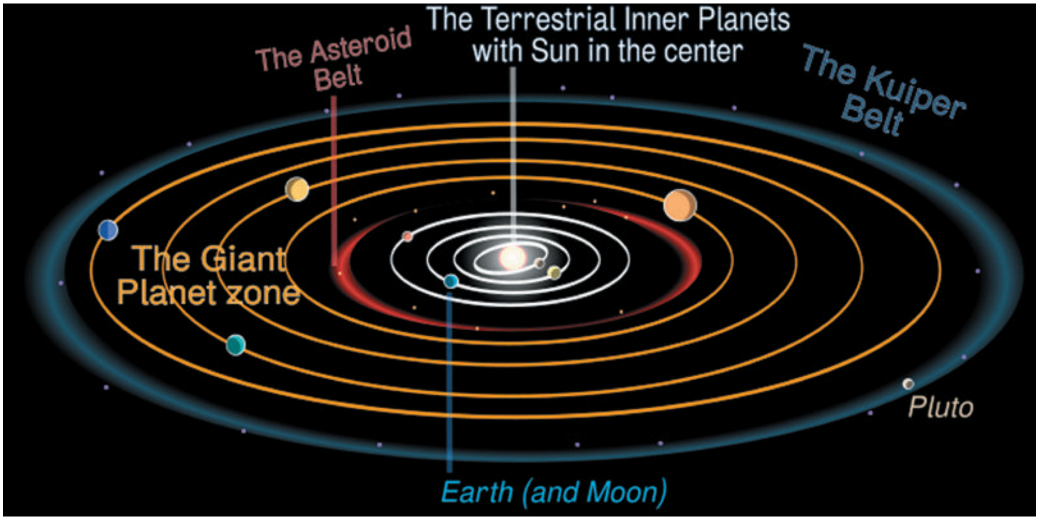

Figure 2-36 - Finally, thanks largely to the "house cleaning" efforts of Jupiter, most (but, unfortunately, not all) of the leftover debris from the accretion process was removed and we have our present home solar system to enjoy. (Image credit: Rursus/Wikipedia Commons)

only reason these gas giants did not get any more massive was that young stars, including the sun, go through a phase (known as the *T Tauri* stage) just before entering the main sequence in which they develop a solar wind that acts to blow away the remaining gases from the accretion disc. **Figure 2-36** shows an artist's schematic view of the final makeup of our solar system once the long violent accretion process was completed and the spaces between the planets was finally emptied of most of the leftover planetesimals and other debris (including most of the remaining hydrogen and helium gas of the original accretion cloud).

However, in spite of the extreme violence involved, the length of time required for the complete formation of a planetary system, i.e., from the first dust particles beginning to stick together to the final stages or end of the "runaway accretion process" is believed to be a relatively short, cosmologically speaking, period estimated to be somewhere between 10 and 100 million years. The earth's accretion process was essentially completed by 4.5 billion years ago (bya). At that time, although the earth was close to its present size, the spaces between the individual planets of the solar system were still extremely crowded by leftover debris from the formation process. It would require close to another half billion years for this material to be cleared away. While much of the remaining debris would continue colliding and fusing with the major planets and their individual moons, the remainder would be catapulted out of the solar system as a result of having their orbits gravitationally disturbed by the planets. Because of its larger and stronger gravitational field, Jupiter undoubtedly contributed the most to this final "sweeping away" process. The period from approximately 4.5 bya to 4.0 bya is known as the *heavy bombardment* period (**Figure 2-37**). During that period, the earth as well as the other newly formed planets existed in a virtual "shooting gallery" in which leftover debris, from the size of the tiniest grains of dust to objects as large as hundreds of miles in diameter frequently

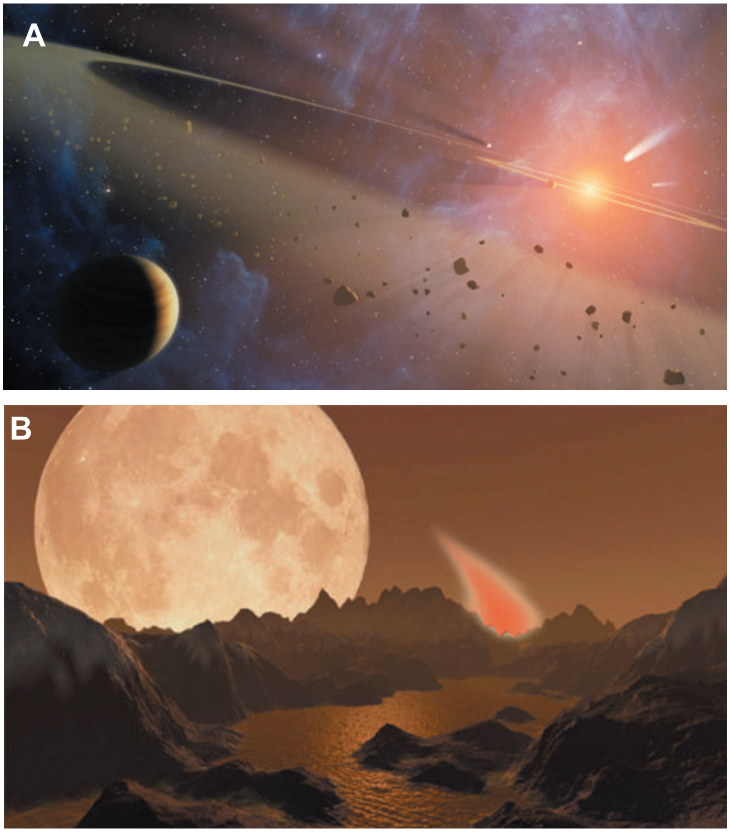

Figure 2-37 - (**A**) Shows an artist's view from space (Image credit: NASAS/JPL-Caltech) as well as (**B**) the earth's surface of the residual "hell on earth" during the Hadean heavy bombardment period (Image credit: NASA/Steve Hobbs). Unfortunately, Jupiter's house cleaning job was not completed real quickly. While all the planets had grown to their current sizes by approximately 4.5 billion years ago, the reign of terror from the skies took at least 500 million more years to calm down sufficiently to allow life to safely begin establishing itself on earth.

collided with the earth and moon (plus the other planets and their moons).[13] The evidence for this heavy bombardment can easily be seen on any clear evening with a small telescope. Our moon is covered with a huge number of craters ranging in size from small to very large (**Figure 2-38a**). These craters (which can also be seen on other planets, such as Mercury and Mars, where atmospheric erosion of surface features has been non-existent or minimal through the ages) are the direct evidence of this intense bombardment period. The earth, being considerably larger than the moon in surface area made it an easier target, while its stronger field of gravity caused it to attract the big boys among the marauding leftover debris. The extreme amount of weather-related erosion plus continual recycling of the earth's surface crust (due to a geological phenomenon called plate tectonics, which will be described in Chapter 4) has destroyed virtually all evidence of large craters on our planet except for a few very recent ones (see **Figure *2-38*b**). In recent years, earth scientists using more sophisticated tools, including sensitive geophysical measurements (e.g., magnetic, radar, and gravitational) obtained from orbiting laboratories, have now been able to identify the remnants of more than 196 ancient impact craters at various

[13]The earth's moon is thought to have been created sometime toward the end of the accretion period as a result of a collision between earth and a large planetismal sized object that may have been as large as the planet Mars (which is 1/10th the size of earth). The collision produced a large field of debris which orbited the earth and eventually condensed into our present moon.

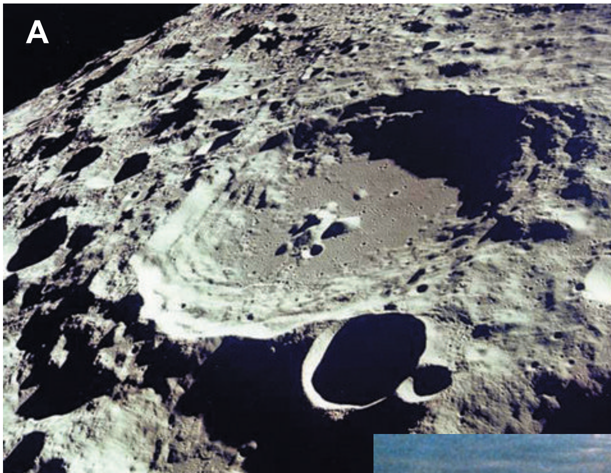

Figure 2-38 - During the latter part of the Hadean period the same rocky debris that was continually striking earth was also hitting our moon and the other planets (and their moons). Viewing the moon with any small telescope (or binoculars) will show (**A**) evidence of this (Image credit: Apollo 11 crew, NASA). While the moon has no climatic conditions that would erode any impact craters, the earth definitely does. **B** shows a photograph of an impact crater in Arizona that looks quite pristine since it is relatively new (estimated to be 49,000 years old) and is located in a dry desert climate that has minimized any erosion effects (Image credits: United States Geological Survey).

locations on earth (**Figure 2-39**). The frequency (rate of bombardment), magnitude (mean size of striking objects), and intensity (damage produced) of the bombardments decreased gradually between 4.5 bya and 4.0 bya. This 500 million year time interval following the completion of the accretion phase of planetary system development, in addition to being known as the heavy bombardment period, is also commonly referred to by earth scientists as the ***Hadean Eon***[14], or the earliest geological time period in the history of earth. Especially during the earlier part of the Hadean Eon, the intense bombardment created so much heat that the earth (as well as the other inner planets) had a molten, or nearly molten surface possibly composed of silicate minerals, aluminum, and other lighter rocky materials, which later cooled to give rise to a solid crust. The intense heat also probably precluded the existence of any atmosphere other than one possibly composed of hot silicate gases. Later, with cooling, the atmosphere of earth (as well as Venus and Mars) came to be dominated by carbon dioxide (CO_2), water vapor, and other volcanic gases. By the end of the heavy bombardment period, there is evidence that all of the inner planets except Mercury (which is too close to the sun and too hot) may have had liquid water on their surfaces.

[14]Geologists and paleontologists have developed a specialized classification scheme that they use to refer to different geological time periods beginning with the earliest Hadean Eon to the more recent Phanerozoic Eon. The term **Hadean** is derived from the Greek word **Hades** for "Hell". The Hadean Eon was indeed a period of "hell on earth" as a result of the continuing catastrophic bombardment from the skies.

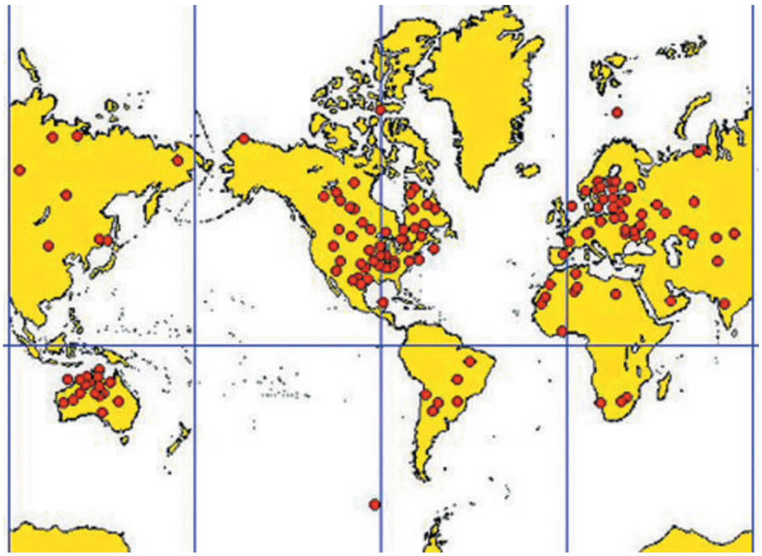

Figure 2-39 - Other than the Arizona impact crater, additional craters on earth have been hard to identify since years of erosion has virtually wiped out any evidence of their existence. However, recent advances in geological search techniques (assisted by special remote sensing technologies onboard orbiting satellites) have found evidence for at least 196 ancient craters. Many more are probably located on the ocean floors where more severe erosion processes have destroyed almost all evidence of their existence. It took many years to identify the existence of the impact crater associated with the asteroid strike that killed the dinosaurs since this crater is mostly located under the ocean off the northern coast of the Yucatan Peninsula in Mexico. (Image credit: FAS.org)

The question of exactly how soon after the end of the "hellish" accretion period life was able to become established is still a "hotly" (no pun intended) debated issue in the life sciences. The intensity of the bombardments, even at the end of the Hadean Eon, was still great enough that most experts agree they were likely to have frequently been life sterilizing in nature. Each time objects as large as several hundred miles across slammed into earth (which was still occurring, although less and less frequently), the surface of the earth would be heated to several thousand degrees Fahrenheit, the oceans would be mostly, if not completely vaporized, and any life that had managed to gain a foothold would be extinguished. It would then require several thousand years (or more) for earth to recover sufficiently (i.e., the surface to cool, the vaporized water to return as rain and refill the oceans, etc.) to again allow for the possibility of another round of "birth of life" events on the surface or deep in the oceans. It is quite possible that the early history of life on earth (and, as we will discuss later, also possibly on Venus and Mars) underwent a successive series of false starts followed by extinctions as a result of these repeated catastrophic events.

Before leaving Chapter 2, the author needs to provide the reader with some additional information about our solar system which has important implications for the development of life on earth as well as possible development of life on other exoplanets. While the relative spaces between the orbits of the planets of our solar system seem to systematically get larger and larger with increasing distance from the sun, there is an unusually big gap between the orbits of Mars and Jupiter. Whereas the planetary spacing pattern would predict the existence of another planet between Mars and Jupiter, there is, in fact, no planet present. What we find instead is a

huge collection of much smaller rocky and metal objects all orbiting around the sun at roughly the same distance. These objects, which are collectively known as the ***asteroid belt***, range in size from that of sand grains to a few inches in diameter to hundreds of miles across, and may number in the hundreds of millions or greater. The asteroids are believed to be the remnants of the early stages of formation of a planet that was aborted as a result of strong gravitational interference from the planet Jupiter. Unfortunately, the asteroids pose a major threat to the security of our planet. These objects are continually bumping into each other which can cause erratic changes in their normal orbits around the sun. Some of these asteroids, when bumped, may alter their orbits and actually cross the orbit of earth, which produces the possibility of a too close encounter (collision) with earth. The extreme speed and size of some of these erratic asteroids could result in massive destruction if such collisions occur. We now know that such an asteroid (possibly with a diameter of 6 to 10 miles) struck the earth approximately 65 million years ago which resulted in massive global extinctions of both plants and animals that included the final demise of the dinosaurs.

Finally, beyond the orbit of Neptune, there exist two additional clouds containing gases, dust, and other objects (**Figure 2-40**). The first, which lies in the same plane as the planets (and is basically an extension of the accretion disc), is known as the ***Kuiper Belt***, and extends a total distance of almost 4 trillion miles. It contains an unknown number of smaller planetoid objects that are mostly composed of frozen volatiles including water, methane, and ammonia ice. Pluto, which was for so long believed to be our ninth planet, is now thought to be one of the largest of the so-called Kuiper Belt *dwarf planet* objects. In addition to the Kuiper Belt, there is an additional cloud of material that extends a distance of close to two light years which is almost halfway to the closest star. Unlike the Kuiper Belt, this ***Oort Cloud*** is spherical (round) in shape. Both the Kuiper Belt and the Oort Cloud contain a large and unknown

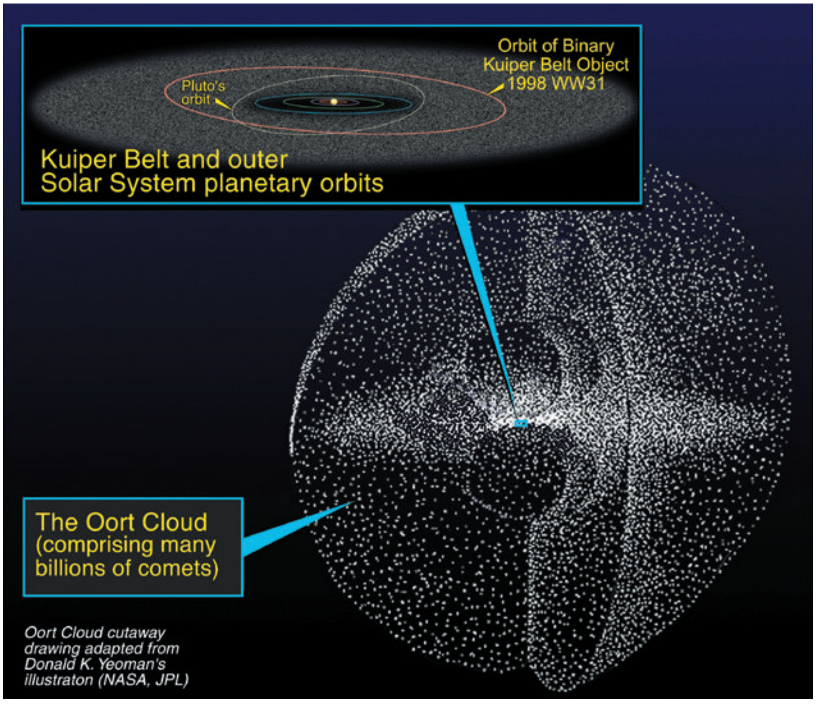

Figure 2-40 - Shows an artist's view of what the smaller elliptical shaped Kuiper Belt and the much larger spheroid shaped Oort Cloud look like. (Image credit: NASA/JPL/Donald Yeoman)

number of special objects known as comets. Those in the Kuiper Belt are known as "short period" (i.e. that orbit the sun relatively more quickly) comets. Comets may exhibit differences in chemical composition depending on where they originate, but in general are loosely packed balls of dust, rocky materials, and frozen water plus frozen gases, including carbon monoxide, carbon dioxide, methane, and ammonia, that exhibit very unusual orbital pathways around the sun. The orbits are extremely elliptical in shape (i.e., very oval shaped or almost flat) as opposed to the more circular orbits exhibited by the planets. Comets start their orbits at huge distances from the sun and then rapidly swing around the sun at a close distance before moving slowly back out into the distant regions of space. The best known comet is probably *Halley's Comet* which orbits the sun once every 75 years (**Figure 2-41**). In contrast to short period comets, the Oort Cloud contains numerous "long period" comets. These comets are so far out in space that they require thousands or millions of years to complete their elliptical orbits. Comets are both a blessing and a curse to mankind. As will be discussed further in Chapter 4, while comets may, on very rare occasions, crash into the earth in the same manner as asteroids, they are also thought to have been a major supply source for some of the critical organic building blocks as well as water needed to build life.

Figure 2-41 - Photograph of Halley's comet, one of probably several million comets that originate from the Kuiper Belt and Oort Cloud. Every 75 years, this short period comet comes in from a region in the Kuiper Belt close to Pluto, makes a sharp turn between the orbits of Venus and Mercury, and then returns to the Kuiper Belt. (Image credit: NASA/JPL-Caltech)

CHAPTER III

HOW LIFE WORKS ON PLANET EARTH

The title of this chapter poses a question that has intrigued and mystified all of us, and especially the scientists and theologians, from the time that man first began moving beyond merely existing and surviving on this planet to contemplating the "meaning" of life. It seems that many people believe they intuitively know the difference between living and non-living matter. When I was in elementary school, my biology teacher told me that life could be defined by seven distinct characteristics. All living things (1) must, in order to survive, take in energy from the outside world (i.e., eat or consume food), (2) excrete waste products. (3) physically move around (walk, run, jump, etc.), (4) grow or change in shape, (5) reproduce, (6) respond to changes in the world around them (get out of the rain, etc.), and (7) maintain a stable physiological state, such as body temperature, in spite of changes in the environment (e.g., the weather). However, my teacher, who was also my Sunday school teacher in a local church, did not make any mention of what is also known to be an eighth characteristic related to "*being able to undergo evolution*". It is now well recognized that certain non-living things may exhibit some of these characteristics, and that some living creatures do not exhibit all of them. Fires "eat", i.e., consume grass, trees, houses, etc., they also grow in size, and they excrete stuff, such as smoke, cinders, or soot, but nobody considers fires to be living entities. Some otherwise living creatures, such as mules, cannot reproduce. Rock crystals can also grow and replicate, and during the middle 1970s some otherwise intelligent and sane people began adopting rocks as house pets. Many years ago, a U.S. Supreme Court justice was asked to define "pornography". His response was that he could not define it, but he sure knew it when he saw it. It seems that is the same response that a large proportion of the general public would give to being asked to define "life". When it comes to knowing what life is, all of us, being citizens of planet earth and having never seen or encountered any examples of extraterrestrial life-forms, cannot help but have a very biased viewpoint. That statement is equally accurate for scientists and non-scientists alike, and most definitely includes the science fiction writers as well. The astrobiologists, while extremely excited about the possibility of being able to someday (hopefully, sooner than later) find bona fide examples of extraterrestrial life to study, are resigned to the fact that they are forced to wear huge blinders when it comes to seeing

the differences between the universal as opposed to the parochial (local, i.e., earth-bound) characteristics of life.

"Definitions of Life" Offered by Life Scientists

Biologists and other life scientists, however, have come up with a fairly comprehensive and solid agreement among themselves as to what constitutes the most important characteristics that distinguish between what life is and what life is not, at least with respect to earth life. Before getting into a somewhat more technical description (but not too technical, I promise) of the fundamental nature of earth life, I will present the results of a quick literature review I performed from which I compiled a brief list of some of the more interesting and relevant definitions of life espoused by investigators in the life sciences. The following set of definitions, descriptions, etc. of what constitutes a living system should be informative for the reader to see:

1. **Life is something that can reproduce itself and evolve through natural selection.** Most scientists are insistent that this "something" must be defined as carbon-based life-forms (or some other biological form) and not mechanical in nature (e.g., mechanical robots). Computer scientists have developed computer programs that can reproduce (create multiple sets of identical lines of computer code). By adding special programming instructions that allow random changes in the code, they can also produce *artificial life* that can actually evolve into other types of computer code. As we will discuss later in the present book, this restriction that life has to be biological in nature may, perhaps beginning as early as the end of the present century, itself go the way of the dinosaurs (become extinct). A few serious scientists believe that this biological to non-biological transition may have already happened in distant parts of our universe.

2. **Some scientists have suggested a three-part definition based on biological evolution.** (e.g., Lewis Dartnell)

   Part 1 - Life must contain a description of itself, an instruction manual, or set of instructions on how it can be rebuilt.
   Part 2 - Individual organisms must be able to carry out the instructions on their own and self-replicate.
   Part 3 - The system must be capable of evolution by natural selection.

3. **In addition to information transmission (i.e., transmitting its DNA instruction manual to its offspring), the organism must extract energy from the outside world to maintain itself.**

4. **Life is a self-replicating chemical system that is capable of evolving so that its progeny or offspring might be better suited to survive and themselves self-replicate.**
5. **Two major properties needed for life are (1) the ability to create order out of disorder by exploiting external energy sources; and (2) the ability to transmit their specific blueprint (for self-construction) from generation to generation.**
6. **Life is any chemical system that is capable of Darwinian Evolution.** (NASA Astrobiology Institute definition)

In the present chapter, I will focus on the specific nature or characteristics of life on earth. One of the truly exciting discoveries of the last half of the 20th century was the finding that life has been present on our planet for a very long time, and quite possibly as long as four billion years. Some tentative evidence has been found for the existence of primitive single cell life-forms as early as possibly 3.8 bya. A few rocks that have survived from that ancient time have been discovered by scientists that contain an unexpected high proportion of a specific type of carbon atom. The element carbon which is the most common atomic element created in dying stars (next to helium) as well as the most common element of all life on earth, tends to take on slightly different forms when it is incorporated into living matter than when it occurs in non-organic (non-living) materials. In addition to 6 protons, the nuclei of carbon atoms typically contains 6 or 7 neutrons (as noted earlier, neutrons serve as the "glue" that holds the protons together, i.e., keeps them from repulsing each other due to their having the same strong positive electrical charges). Atoms with differing numbers of neutrons are referred to as *isotopes*. Carbon which has been incorporated into organic (living) materials tends to be the lighter isotope (with 6 neutrons) as opposed to the heavier variety (with 7 neutrons). It seems that life prefers the less heavy isotope since it allows chemical reactions to occur faster and more easily than would be possible with heavier isotopes. Some 3.8 billion year old rocks that scientists have found in Greenland contain a larger proportion of the lighter variety of carbon which suggests that they might be the remains (chemical fossils) of early life-forms. Even more definitive evidence for early life has been found by paleontologist J. W. Schopf in Western Australia In rocks estimated to have formed more recently or about 3.5 bya. These slightly younger rocks (if you dare consider something that differs in age by 300 million years as "younger") have been determined to contain not only enriched deposits of lighter carbon isotopes, but also small round cell-like structures that might be the fossilized remains of the membranes or cell walls (**Figure 3-1**) of individual single celled organisms. This finding that life may have been able to rapidly gain a foothold on our planet at the earliest possible moment when the devastating early bombardment had settled down, is one of the discoveries of the last half of the 20th century that is fueling the current excitement among astrobiologists. If life is able to originate so quickly (and possibly even re-originate repeatedly) in extreme hostile environmental conditions such as existed on the early earth, how uncommon can life be in the universe?

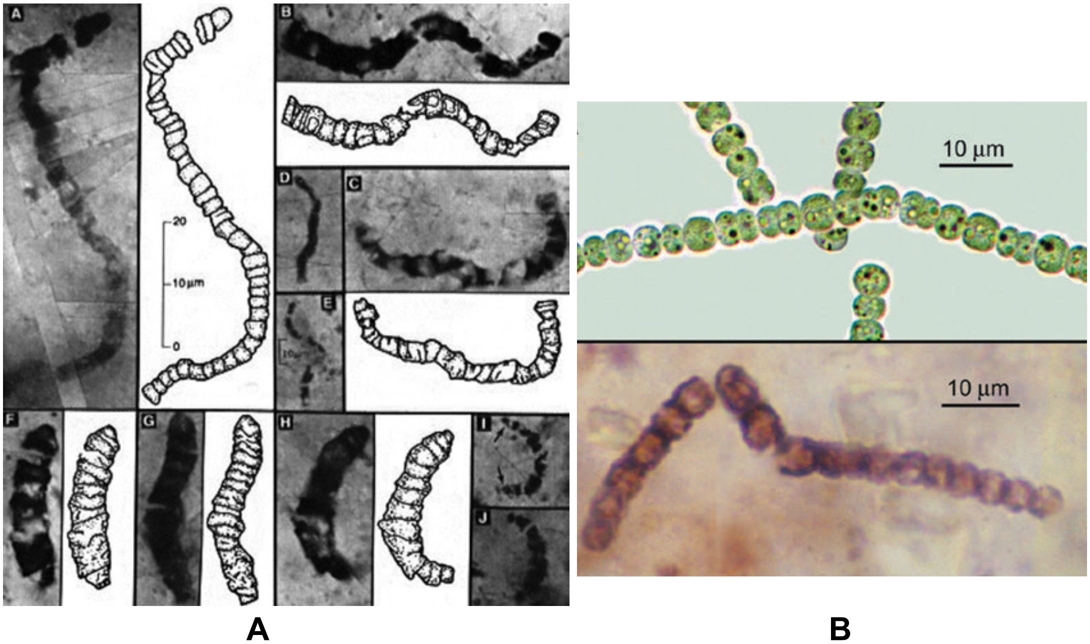

Figure 3-1 - A. Microscope photographs of what are believed to be fossil bacteria found in 3.5 billion year old rocks in Western Australia by Paleontologist J.W.Schopf, The accompanying drawings illustrate the structure of the fossils more clearly. **B.** Photomicrographs of modern living cyanobacteria (top) and a fossilized cyanobacterium (bottom) similar to those shown in A. (Images courtesy of Dr. J.W. Schopf)

While scientists have learned a tremendous amount since the early 1950s about what life (at least earth life) is and how it works, we still know very little about how life may have first originated on our planet. This is largely due to the fact that the extreme "hellish" environment that existed (or, more accurately, "came and went" as a result of the intermittent bombardments) during much of the Hadean Eon totally prohibited the survival of any physical evidence that could today provide clues as to what may have happened. No rocks survived the extreme heat of that time and those that did were long ago ground to a pulp by subsequent upheavals associated with the continual movement and recycling of the earth's crust into and out of the hot subsurface of our planet. What is especially frustrating for scientists is the incredible fact that the earliest life-forms that we have any substantial knowledge of are **not primitive, in any sense of the word!** The earliest life-forms thus far discovered, although limited to extremely small (microscopic) single cells were incredibly complex.[1] These tiny cells were very likely

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[1] The reader needs to understand that it is not possible for scientists to actually study or dissect the fossilized remains of the earliest single cell organisms to determine what kinds of molecules or chemical structures were present inside the cells. The best that scientists today can do is to carefully examine modern descendents of these primitive creatures to determine how they are constructed and how they function. Extensive research performed in recent years has, however, provided evidence that the first cells that lived 3.5 bya most likely were anatomically and functionally very similar to those that are alive today.

filled with literally millions of individual atoms that were bonded together into an extremely large number and sophisticated variety of large molecules each consisting of hundreds of atoms that allowed their owners to carry on most of the major life functions that we see in modern species. (In the present book the author will refer to such giant molecules as *macromolecules*, in which the suffix "macro" is defined as "large".) The way in which these primitive organisms extracted energy from the environment, the way they obtained the food they needed to live, grow, and replicate, plus the way they evolved in response to changes in the environment, were most likely very similar and in many cases identical to how these tasks are accomplished by modern organisms. It is as if a boating enthusiast decided to begin investigating how boats originated on planet Earth, only to discover that the most primitive fossilized remains of the first boat-like crafts that could be found were not rafts (logs tied together that float on water) or even primitive canoes (or "pirogues" as they are referred to in Louisiana, that are actually nothing more than hollowed out logs from large trees), but machines as sophisticated as sailing or steam ships. Therefore, scientists interested in unraveling the mysteries of how the first life originated on our planet are faced with a major dilemma. It appears that the first critters that were able to leave any documented evidence of their existence were ones that had already, in a time period as short as a few million years (or even shorter), gone through an amazing amount of evolutionary development.

Thus, in spite of the tremendous advances made during the second half of the 20th century in our understanding of the specific nature or characteristics of life, scientists today remain virtually clueless with respect to understanding the process by which the very first living creature originated on our planet. While most people (including many scientists) had, for hundreds of years, believed that life spontaneously originated from non-living matter, Louis Pasteur totally destroyed this belief in some experiments he conducted in 1862. Pasteur convincingly showed that life could only originate from other pre-existing life. The reason that maggots spontaneously pop up in rotting garbage is because flies lay their eggs there. Get rid of the flies and the maggots will not appear. To prevent food from spoiling, place it in an air tight jar to prevent bacteria from getting in or heat the sealed jar to kill any bacteria that might have already managed to sneak in. Unfortunately, Pasteur's experiments (and those of many subsequent scientists) handed our scientists a mind boggling enigma. If all life has to arise from pre-existing life, where did the very ***first*** life come from? Scientists were now forced to focus on discovering the complicated series of steps or stages by which non-organic molecules were able to eventually transform "themselves" into replicating organic molecules. This origin of life problem is today being actively investigated by a growing number of specialists within the new field of astrobiology. Although a large number of interesting and sometimes provocative theories have been proposed (including the somewhat "tongue-in-cheek" suggestion by James Watson, who broke the DNA genetic code, that extraterrestrials may have actually "planted" the first life on earth) by different investigators as to how this non-life to life transition may have occurred, very little hardcore research data has been uncovered thus far. Since so little is presently known

about this fascinating origin of life topic, in the rest of this chapter plus the remainder of this book, we will limit our discussion to providing an overview of what we believe we do know, and that is the unique chemical and physical characteristics that distinguish life as we know it today on earth from non-living matter. In contrast to the question of how life originated from non-life, our life scientists were able to make a great deal of progress during the second half of the 20th century in this exciting area. So, readers, buckle your seat belts -- the remainder of this chapter will definitely not be boring! I will begin by listing and briefly describing each of several characteristics that seem to uniquely separate living from non-living matter.

LIFE ON EARTH IS PACKAGED INSIDE SMALL CONTAINERS THAT RESEMBLE BAGS OR SACKS

This is probably the most recognizable and widely known characteristic of life on our planet. Just as the reader and the author need strong houses to protect us from extreme weather conditions, all life must be housed inside some kind of protective structure, which is absolutely critical to keep an extremely unfriendly and hostile outside world from totally destroying the extremely complex and delicate life processes that must chug along at virtually full throttle all the time. Probably the most amazing characteristic of living matter is its ability to protect itself, when necessary, by totally isolating itself from the outside world (i.e., by staying *out of equilibrium* with it) while, at the same time, interacting with the outside world to obtain what it needs to live as well as throw away what it must in order to stay healthy. Staying out of equilibrium means that the organism must constantly make sure the complex physical and chemical environment *inside each of its cells* remains different from that of the world that surrounds it. The only time an organism becomes truly *in equilibrium* with the rest of the world is after it dies. Following death, the organism's internal state starts to merge (i.e. return to a state of equilibrium) with that of its environment. The act of constantly staying out of equilibrium with the outside world requires lots of energy which must be readily available at all times.

The "bags or sacks", which house all of life's critical physical and chemical components, are more commonly referred to as ***cells***. These cells can serve as the dwellings for single independent free-living organisms (i.e., as single-cell organisms with ***bacteria*** probably being the most familiar example), or as groups or collections of individual specialized cells that are physically attached to each other and which work together (somewhat analogous to an organized "athletic team") to form more advanced and complex multi-cellular organisms (e.g., plants or animals). While cells may be the basic structural units of all living critters on earth, they do not all look alike when viewed under a microscope. Significant structural as well as functional differences exist between different cells depending on whether they are primitive or advanced forms of single-cell life or whether they are components of complex multi-cellular organisms. I will first describe the unique features that scientists believe was probably exhibited by the first single-cell creatures that appeared as fossils in rocks some 3.5 bya.

All cells, whether being of the single-cellular or multi-cellular variety, are filled with a somewhat watery or gel-like fluid called ***cytoplasm*** that contains all kinds of incredibly complex life processing chemicals. The lining of all individual cells consist of an extremely thin (less than a millionth of a centimeter thick) cell membrane that provides the critical first line of defense in protecting the delicate and complex life processing innards of the cell. The cell membrane also contains biologically controlled pore-like structures ("holes" or "gates") that can be opened or closed to allow the entry of specific chemicals that are needed from the environment as well as the ejection of metabolic waste products to the outside. In addition to a cell membrane, which is quite flexible plus fragile, many cells also have a thicker more rigid cell wall that provides even greater protection as well as structural support (i.e., keeps the cell literally from getting bent out of shape). The fluid inside the cell contains a rich assortment of complex chemical "factories" that allows the organism to combine energy extracted from the outside world with specially imported chemical molecules to produce and/or digest food with which to feed itself, as well as construct replacements for worn out parts. Most importantly, the tiny cell also contains the critical machinery that allows it to grow and reproduce as well as evolve (by altering the genetic blueprint of succeeding generations) in order to adjust to a changing environment.

First "Primitive" Single-Celled Organisms

While the first life-forms to develop on earth were quite small and single-cellular, these organisms were definitely not simple. The discovery in the early 1950s that all life on earth uses the same basic *operator's manual* (i.e., gigantic DNA macromolecules and the same genetic code) for all life functions led, beginning in the late 1970s, to a completely new and more accurate method for determining the family relationships among all creatures on earth, i.e. for determining who is related to who and who descended from who. Carl Woese was the pioneering scientist who launched this major breakthrough in classification of family relationships. While earlier classification schemes had relied on observation of distinct physical (i.e., morphological features, i.e., "what they look like") or functional differences ("how they act, what they do") between different organisms to form family trees composed of hierarchical subdivisions called *kingdoms*, *orders*, *families, species*, etc., in the latter part of the 20th century scientists developed powerful new tools to identify subtle differences in the genetic makeup of individual organisms. It has now become possible to develop complex maps of all the genes (which, in different types of organisms, may number in the thousands) that collectively control all of the life functions (feeding, growth, reproduction, evolution, etc.) of the members of any given species of organism. By performing complex analyses of what genes are present or absent in a given organism, and identifying which ones are different or changed from one group of organisms to another, scientists are able to draw a picture of how different species are related

to each other. These complex maps of the ***genome*** (a term which refers to the collection of all the individual genes of a given species) have produced far more accurate and complete family trees than was possible with earlier classification schemes that were based on far less reliable differences in physical appearance or function.

For well over three-quarters of the history of life on earth, single celled creatures were the only show in town. The transition to multi-cellular life-forms occurred relatively late in this long history. From life's earliest beginnings up to the present day, single cell species have continued to be by far the most dominant life-form on planet earth. In terms of numbers, single cell organisms outnumber multi-celled organisms by a ratio that is totally mind boggling, if not incomprehensible. Each and every individual human (as well as other animals, and also plants) on the planet has millions of different single-cell organisms living inside their intestines (as well as other body parts). It is also estimated that, if we could take all of the members of the two basic types (i.e., single and multi-cellular forms) of organisms that exist today on earth and weigh them on a scale, single cell critters might actually outweigh multi-celled forms. In addition to being the dominant life-forms in terms of bulk, single cell life-forms are far more critical to the survival of life on earth than are multi-cell forms. While some bacteria and other single-cell organisms do have a nasty reputation for causing disease and death among multi-cell forms, the vast majority of such single-cell organisms are beneficial to the survival of the so-called higher life-forms. If all single celled species were eliminated from earth, man and all other multi-celled plants and animals would be doomed to immediate extinction. Take the higher life-forms away, and most single-cell organisms would do just fine (or better, in many instances). Many scientists believe that, at present, the most dangerous life-form on earth with respect to the future survival of all life is the multi-cellular species that calls itself "man".

The pioneering genetic mapping research of Carl Woese and his students resulted in the identification of three distinct types of single-cell life-forms (**Figure 3-2**). Probably the most primitive form is referred to as ***Bacteria***. These organisms are very tiny, sometimes being as small as 1/1000 of a millimeter (one millimeter equals .04 inches) in diameter, or even smaller. In contrast to more advanced single-cell organisms (which we will describe shortly) the watery or gel-like contents (cytoplasm) inside the cells of bacteria do not, under the microscope, appear to have any evidence for being divided into differentiated forms or structures. All of the chemical ingredients needed to carry on life functions, including the genetic DNA material, seem to be free-floating in the gel-like substance of the cell's interior. Another primitive single cell life-form which, under the microscope appears very similar to bacteria is labeled as ***Archaea***. This type of cell evolved after the bacteria. The bacteria and the archaea are collectively called the ***Prokaryotes***, a term that means "absence of a cell nucleus", a characteristic that the two life-forms have in common.

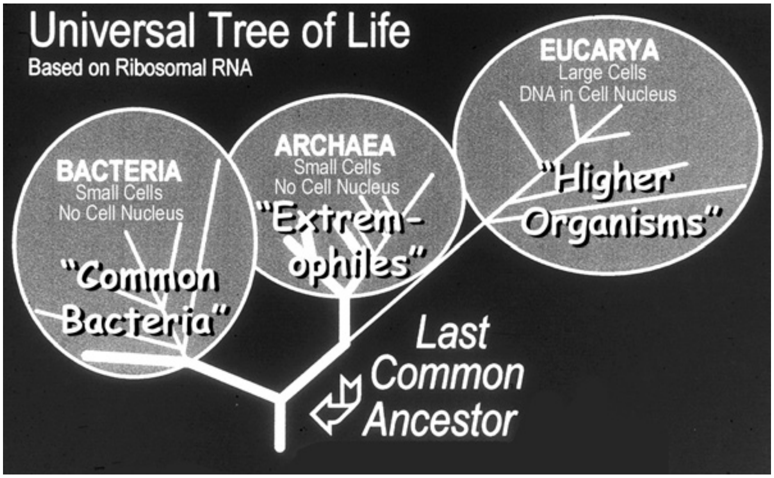

Figure 3-2 - Scientists today determine the family relationships among different plant and animal species by identifying how ribosomal RNA is modified and passed from generation to generation rather than relying on what organisms look like or how they function (or behave). (Image credit: Dr. J.W. Schopf)

Modern Single-Celled Organisms that Live and Thrive in Extreme Hostile Environments

One of the truly fascinating events of the late 20th century was the discovery by scientists that many of the archaeas (as well as some bacteria) are not only still present on our planet but still prefer to live in extreme environmental conditions that would be totally intolerable for higher multi-celled life-forms to live in. These strange critters have been labeled by scientists as ***extremophiles*** (i.e., lovers of extreme environments). In addition to the discovery of exoplanets in the second half of the 20th century, it was the discovery of the extremophiles that launched the new scientific discipline of astrobiology. Since the discovery in the 1970s of heat loving microbes that live near the deep sea hydrothermal vents, scientists have been discovering more and more bizarre life-forms that live in all sorts of extreme environments. What is fueling the excitement among the astrobiologists is the possibility that the extreme environments that many of earth's extremophiles call home are similar, if not identical, to environments that are thought to exist on other planets and moons in our own solar system as well as other locations in the universe. Some scientists now actually believe it is possible that some of these extremophiles might be able to survive if transported to Mars or other locations in our solar system.

During the past 30+ years, the search for extremophiles has been extremely prolific. Since the late 1970s, scientists have been busy discovering further varieties of these strange lovers of extreme environments. They live in all kinds of incredibly non-friendly locations including extremely hot, cold, salty, alkaline, acidic, dry, high pressure (deep below ground and deep in the oceans), and even radioactive places (inside the coils of nuclear reactors). They are able to thrive in the boiling and highly acidic waters of the hot geysers at Yellowstone National Park (**Figure 3-3**), in the extremely dry and thin atmospheres on top of tall mountains where they are continually bombarded by deadly ultraviolet radiation from the sun, and even in rocks located several miles below the earth's surface. (I*n fact, some scientists, e.g., Thomas Gold, have proposed the startling idea that the total mass of*

Figure 3-3 - Photograph of one of the many boiling hot geysers found in Yellowstone National Park. These geysers are home to the so-call hyperthermophile forms of single cell life that actually make their home in boiling water. (Image credit: Wikipedia Commons)

creatures that live below ground may exceed that of those that live above ground.) Microbes have even been found living in frozen icebergs. Extremophiles seem to be found almost literally "everywhere". The only exception seems to be completely arid (total absence of water) and the vacuum of outer space, although some of these organisms have managed to evolve adaptive mechanisms that allow them to go into special suspended animation or hibernation states for periods of time in order to survive in even these ultra-extreme environments.

The number of different varieties of these strange creatures appears to be large. It seems they can tolerate almost any kind of extreme environmental conditions as long as some kind of energy source is available to fuel their metabolisms and they are allowed to have access to carbon and water. **Table 3-1** provides a detailed listing of many of the different kinds of extremophiles so far discovered as well as a brief description of the unique nature of the environments in which they live. In the next chapter of this book (Chapter 4), I will present a much more indepth description of one variety of these extremophiles known as the thermophiles (i.e., lovers of hot environments) which some scientists believe might be the direct descendents of the earliest common ancestor of all current life on Earth, including mankind.

ARRIVAL OF LARGER "COMPLEX" SINGLE-CELL ORGANISMS

Sometime between 1.7 and 2.2 billion years following the development of the first two types of so-called "primitive" single-cell organisms, a physically much larger and more complex variety of single-cell organism arrived on the scene. In contrast to the prokaryotes (archaea and bacteria), which relied on an anaerobic lifestyle (not needing oxygen to life), these organisms, which are collectively labeled the ***eukaryotes***, took advantage of the later development of high concentration levels of free oxygen in the atmosphere to fuel a much more efficient form of metabolism. In addition to being as much as 10 times larger in diameter, some eukaryotes are even visible to the naked eye (**Figure 3-4**). When the gel-like contents of these large cells are examined with a

Table 3-I. Earth life that has adapted to extreme hostile environments

Extremophile Type	*Brief Description of Environment in which each Extremophile lives*
Hyperthermophile	Live in boiling water near volcanic hot springs such as Yellowstone National Park.
Thermophile	Live in hot or near boiling water at deep sea hydrothermal vents.
Psychrophile	Live in extreme cold conditions such as Artic or Antarctic, even inside ice bergs.
Atomophile	Live in high radiation areas such as on control rods at nuclear power plants.
Pizeophile	Can tolerate extreme pressure such as deep underground or deep sea locations.
Xerophile	Live in extremely arid (dry) environments such as Death Valley, California.
Halophile	Live in extreme salty water conditions (much saltier than normal sea water).
Alkaliphile	Live in extreme alkaline water such as soda lakes (household ammonia).
Acidophile	Live in extreme acidic environments such as sulphur springs (lemon juice).
Anaerobe	Cannot live in environments containing free oxygen.
Microaerophile	Can tolerate extremely low oxygen conditions.
Radiaresistant	Resistant to high levels of ionizing radiation, such as ultraviolet radiation from sun.

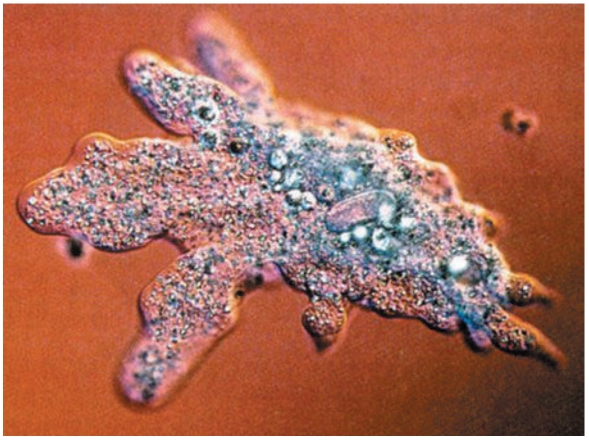

Figure 3-4 - Some single-celled eukaryotes have, in contrast to their simpler prokaryote cousins, become large and quite sophisticated. Shown is a photograph taken through a microscope of one such organism, known as an Amoeba. (Image credit: public domain)

microscope, scientists find a very complex degree of structural organization that is in marked contrast to the very bland appearance of prokaryotes. The interior of these cells is filled with a variety of what appear to be wall-like or skeletal-like partitions as well as smaller cell-like structures of different size, each with its own complex internal organization. The largest of these internalized cells is labeled the *cell* ***nucleus***. This structure serves as the *central information or command center* for the organism which houses all of the DNA and genetic material. Numerous other small internalized cell-like structures are present which serve to house other specialized systems (sometimes called "factories") needed for the complex life functions of the organism.

One of these is called the ***mitochondria***. This small cell-like entity (frequently referred to as *organelles*, meaning "small or miniature organs") is the *power house* (or kitchen) for the organism and contains all the chemical materials and structures needed to extract energy from fuel (food) in order to power the biologic activities of its owner. A second common organelle found in some organisms is one labeled the ***chloroplast***. This structure exists in plants and contains all the chemicals needed to allow the plant to transform light energy from the sun into biologic energy forms that are needed to fuel the plant's activities. **Figure 3-5** shows the major structural differences between prokaryotes and eukaryotes.

The arrival of the Eukaryotes marked a major step forward in the evolution of life on earth. The eukaryotes not only allowed single celled organisms to engage in more complex and versatile lifestyles than was possible for their prokaryote predecessors, it also opened the door to the very rapid development of the even more complex multi-cellular life-forms. The nature of the transition from prokaryotes to eukaryotes is a fascinating story in and of itself. Many scientists, including Lynn Margulis, believe that the different organelles found inside the eukaryotes were originally free-living bacteria that somehow got engulfed inside an early eukaryote (perhaps originally intended to be a meal), but instead of being digested, they stayed around long enough that mother nature discovered that some bit of their biologic or metabolic

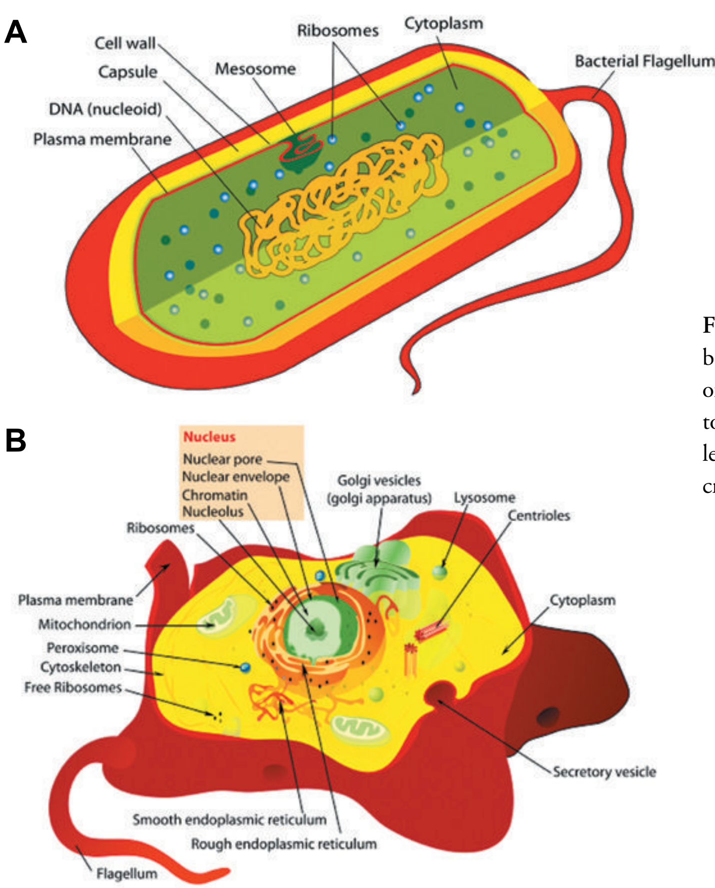

Figure 3-5 - Contrasts the basic differences between **A** prokaryote and **B** eukaryote forms of single-cell organisms. These drawings are not to relative scale since eukaryotes are typically at least ten times larger than prokaryotes. (Image credits: LadyofHats/Wikipedia Commons)

activity was actually beneficial to the eukaryote. Instead of being digested or ejected, this bacterial cell (new "tenant") linked up with the eukaryote ("landlord") in a mutually beneficial partnership labeled a symbiotic relationship. ***Symbiosis*** is a relatively common feature of the biological world (i.e. "If you scratch my back, I'll scratch yours"), ranging all the way from the bacteria in our intestines that trade us much needed vitamins for our protecting them from the lethal effects of oxygen, to bees assisting the reproductive process (pollination) of flowers as trade for receiving the tasty foodstuff called nectar. Following the merger of the eukaryote and the prokaryote cells, the landlord cell (over time) took over some of the critical biologic tasks needed by the tenant itself to stay alive and healthy in order to provide more time for it to do its new "communal" service work (e.g., metabolizing food that both it and its landlord needed to stay healthy).

Explosion of "Complex" Multi-Cellular Life-Forms

The next stage in evolution was the transition from independently living single cell organisms to various kinds of "group living" or multi-cellular forms of life. As far back as the Archean Eon, some species of bacteria (e.g., cyanobacteria) began to inter-mingle to form so-called ***colonies*** consisting of large numbers of individual single-cell organisms. At first, these colonies were nothing more than loose associations of individual organisms that came together for mutual protection and to share common environmental resources. Such colonies were the early precursors of what would later develop as the true multi-cellular/multi-specialty forms of lifestyle. In some of these early colonies, there was in fact some specialization of function by individual members of the group, although for the most part, this specialization was only minimally related to biological or genetic factors. Colonies of individual organisms still exist today, although the specialized functions of individual members of many of these colonies has now become more biological or genetically determined. For example, many of today's insects, including the ***ants***, with their individual castes of soldier, nurse, and queen ants carry on this type of colony-type lifestyle.

Finally, after the early colonists came the true multi-cellular creatures of the world. The author will not spend much time describing this basic characteristic of earth life, since whole libraries are filled with excellent books and other educational materials that the reader can access if they feel a need to learn about these more advanced lifestyles. Virtually everything I have discussed thus far in this chapter related to the unique characteristics of "cellular life" continues to hold true when we turn to considering the uniqueness of multi-cellular life. The most important difference is that, with the coming of true multi-cellular life, cells had to become less of a "jack of all trades" (i.e., carrying on ***all*** of the individual organism's life functions) and take on a "team member" role as one component of a larger tissue or organ system that now performed very specific (but life critical) tasks. Individual cells now, in addition to becoming

specialists in terms of carrying on specific biologic tasks needed by the larger organism as a whole, also had to rely on the activities or biologic products of other specialized cells (in other organ systems) for their survival.

DIFFERENT LIFE-FORMS ON EARTH USE DIFFERENT METHODS TO FEED THEMSELVES

The individual members of all life-forms must possess the ability to self-build or self-construct themselves. All life must extract energy and raw materials from the environment in order to feed themselves, grow and multiply, replace worn out parts, plus respond to short term environmental changes and adjust, via evolution, to longer term environmental alterations. Most life-forms must constantly keep their internal metabolic factories going 24/7 or they risk death. There are, of course, a few exceptions to this rule in which some organisms can temporarily shut off or throttle down their factories through specially evolved mechanisms that allow them to become dormant or hibernate for periods of time. However, in spite of such temporary "time out" periods, these metabolic factories were turned on by the very first living cells and have been going virtually non-stop ever since. Every cell in the reader's body (and the author's) is linked directly in a non-stop continuous manner to the original "Adam and Eve" of all life, the first living cell that popped up sometime between 3.8 and 4.0 bya. And this first cell, in turn, was directly linked (again in a non-stop manner) to a totally unknown series of prior continually changing pre-biotic entities (e.g., self replicating inorganic molecules) that were on their way to evolving into the first prokaryote cells.

Life on earth has derived a large number of independent ways to obtain the building materials plus the energy resources it needs to stay alive and healthy. In order to do this all life-forms must continually feed themselves. We will begin our discussion with the example we are most familiar with, and that is how animals and plants feed themselves. Feeding is the means by which animals and plants obtain both the energy and the raw materials (chemical building blocks) they need to live, grow, and reproduce. On earth, these building blocks are relatively small organic molecules (typically containing no more than 10 to 30 atoms) usually made up primarily of hydrogen, carbon, oxygen, and nitrogen, plus occasional smaller amounts of phosphorus, sulfur, and other critical elements. Biochemists tell us that all earth life is constructed from approximately 50 such small organic molecules or substances that, for example, include sugars, amino acids, fatty acids, nitrogenous bases, plus additional specialized molecules. Altogether, these 50 or so basic organic molecules make up more than 99 percent of the organic components of all earth life. Water, of course, must be included in this list, as it is always the principal component (man, as an example, is composed of a little over 60 percent water). Water provides the critical medium which is needed to allow the chemistry of life to operate. Atoms float around in the water filled interiors of cells and bond together with other floating atoms to form simple and complex molecules. Life also contains a small percentage of

non-organic substances including, sodium, potassium, chlorine, calcium, iron, and a few other elements.

Plants and animals use different methods for gathering the organic building blocks they need to survive. Animals use a technique called ***heterotrophy*** (literally, feeding on others). Animals consume other animals, or plants, that have body parts constructed from the very same kinds of organic molecules or building blocks as their own bodies. However, the functional parts of all plants and animals are composed of giant macromolecules that are typically made up of long chains or strings of the different types of simpler organic molecules or building blocks. These gigantic macromolecular entities, which are more commonly called tissues, may contain millions of individual atoms. One of the most common types of tissues in all animals is one that is referred to as ***proteins*** by biochemists. Proteins come in a large number of different forms and are all made up of long chains of a basic type of building block known as *amino acids* (**Figure 3-6**). While, in nature, approximately 100 different amino acids are known to exist, all animal life on earth is built from combinations of the same subset of 20 different amino acids selected from this larger pool. Proteins are truly the "work horses" in the organization of animal life on our planet. A huge number and variety of special proteins known as ***enzymes*** act to organize, direct, and speed up the vast majority of the chemical reactions that occur inside the living cell. Proteins are centrally involved in all of the different life functions of the cell including the construction of biological structural components (skin, muscle, organs, toenails, etc.), growth and replication, plus digestion and other metabolic processes. When animals eat plants or other animals, they consume these proteins (plus other types of tissues), which must then be digested or broken down into their component building blocks (e.g., simpler organic molecules like amino acids, fatty acids, etc.) before they can be used by the animal's own chemical factories to link these simpler organic molecules together to build their own proteins and assorted tissues that they need to stay alive and healthy.

Plants, in contrast to animals, use a different method to obtain the critical building blocks they need which is known as ***autotrophy***. Our familiar house and garden plants are hooked

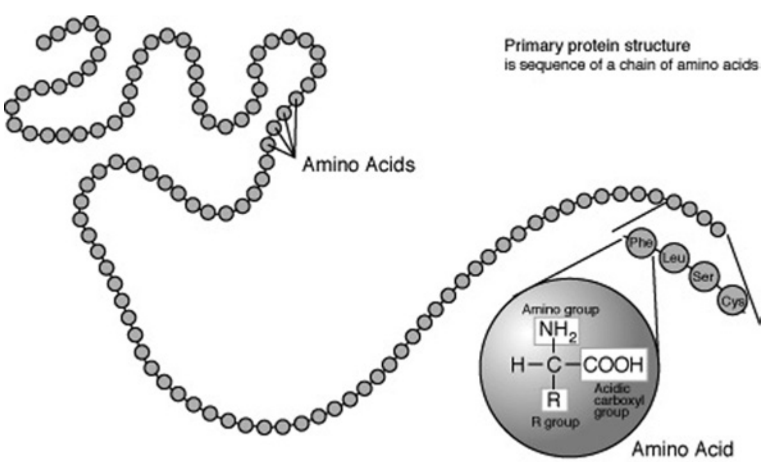

Figure 3-6 - Proteins are made up of strings of individual amino acid macromolecules linked together to form a long chain. (Image credit: National Human Genome Research Institute)

on this lifestyle. Instead of getting their building blocks by eating other organisms, plants typically construct their own organic building blocks out of non-living materials gathered from the environment. Plants have developed a complex biological process called ***photosynthesis*** which is what the organelles called *chloroplasts* in some eukaryote cells do. Plants take carbon dioxide (CO_2) from the atmosphere and insert it into the chloroplasts located inside the cells of their leaves. Then, a complex chemical called *chlorophyll* is used to absorb and convert solar radiation from the sun into chemical energy which then takes the carbon from the CO_2 and combines it with H_2O to produce carbohydrates (sugars) and oxygen. The carbohydrates are then used as the energy (food source) the plant needs to synthesize the organic chemical building blocks they need for growth and reproduction. As will be discussed later, plants and animals exhibit the "mother of all symbiotic relationships" on earth. In driving their metabolic factories, a major waste product that animals throw away (eject) is CO_2, while plants throw away excess oxygen as a waste product when carrying on their photosynthetic thing. Since animals require oxygen to stay alive, and plants need carbon dioxide to live, each life-form considers the other a "good neighbor".

Most of us that managed to survive our high school or college biology classes are relatively comfortable with how plants and animals feed themselves and obtain the energy they need to fuel all their biological processes. However, as we now know, plants and animals are not the dominant forms of life on earth in terms of population census numbers and, most definitely, also not in terms of seniority. Single celled organisms, especially prokaryotes (*bacteria* and *archaea),* comprise far and away the largest bulk of living matter on the planet, plus being by far the oldest forms. Many of these organisms originated on earth at a time when it was quite hot and there was not yet any oxygen to breathe. It is no surprise that many of these primitive creatures developed lifestyles that were markedly different from that of modern plants and animals. These early prokaryotes did not directly consume (eat) organic molecules or need sunlight to build their own organic molecules that they needed for food. This somewhat strange lifestyle (strange to us but probably not strange to the majority of earth's life-forms, i.e., the prokaryotes) is labeled ***chemotrophy***.

Many scientists now believe that the first life-forms on earth, i.e. the "common ancestor" of all of our modern plants and animals, were probably the heat-loving thermophiles whose direct descendents today still live near the hot hydrothermal vent systems deep in the oceans. Since the late 1970s, scientists have been busy studying these creatures to determine how they manage to obtain the energy and food resources they need to live. In contrast to modern-day plants and animals, these first critters (as do their modern descendents) used a different process to feed themselves. All carbon-based life, including the thermophiles, rely on the "*big four*" elements of hydrogen, carbon, oxygen, and nitrogen to live. All organisms require organic molecules for food. Organic molecules are ones that contain carbon and hydrogen. Some common types of organic molecules are carbohydrates (sugars and starch), lipids (fat), and proteins. Whereas animals eat other animals (or plants) to obtain these critical molecules and plants use sunlight

as an energy source to themselves manufacture these molecules from inorganic molecules (i.e., carbon dioxide and water), many of our early heat loving microbial ancestors obtained both the chemicals and the energy they needed to live from deep sea hydrothermal (volcanic) vents. The hot water escaping from these vents contains large concentrations of inorganic minerals such as hydrogen sulfide that can be used as an energy source by the extremophiles to build (or synthesize) their own organic molecules that they require for food. Thus, while animals obtain their food by eating other animals or plants, both plants and thermophiles must use some kind of outside energy source to build their own food from inorganic molecules. While plants use sunlight to do this, extremophiles take advantage of the energy that is provided whenever hot water and certain types of dissolved minerals (e.g. sulfur compounds) get mixed together at the deep sea hydrothermal vents. The deep-sea vents are associated with undersea volcanoes (and tectonic plate activity, to be described in the next chapter) that is constantly spewing out water that is heated to high levels by magma rising from the hot interior of the earth. The water from these hydrothermal vents is chemically quite different from the surrounding sea water. Whereas the rising vent water is hotter, more acidic, and more chemically reduced (i.e., contains lots of negatively charged electrons) than the ocean water that surrounds the vent system, it is also saturated with high energy inorganic mineral compounds such as hydrogen sulfide. The mixing of the two kinds of water provides both the chemicals plus the energy source the thermophiles need to build their own food. The very first life on earth (plus, many of their modern day descendents), therefore, did not need sunlight as its energy source, but only access to an unstable chemical environment courtesy of geothermal heat rising from the earth's hot interior. This suggests that earth life is incredibly flexible (innovative, tenacious?) in terms of "how and where" it manages to obtain the energy and food resources it needs to exist.

All Life-forms on Earth Use Same "Chemical Power Generator" to Perform Biological Work

In the last section of the present chapter, the author discussed the many different ways that life-forms on our planet obtain the food they need to live, grow, and reproduce. I will now describe how all life-forms on earth use the exact same chemical process to perform the *biological work* that is continually involved each and every day in the act of actually liv**ing**, grow**ing**, and reproduc**ing**. In the biological world, obtaining the energy and food resources that will allow life-forms to live, grow, and reproduce is totally different from the process of "fueling" the actual daily biological work that is required to perform these critical functions. The reader is undoubtedly very familiar with the large number of ways in which non-living matter uses energy to carry on specific functions. Cars use oxygen to burn gasoline (fuel) inside combustion engines to produce heat which then pushes pistons to make the car move. Electric power plants take the energy from other sources (e.g. falling water at dams, heat energy produced by

burning coal, nuclear fission, etc.) to create electrical energy in the form of negatively charged electrons which are then shipped out, via electric company power lines, to homes where the electrical energy is used to cause lamps to light up, televisions to turn on, etc. Thus, while automobiles need immediate access to energy (e.g., from burning gasoline) to "do their work", every living creature on earth (plants, animals, bacteria, and even extremophiles) must have a constant supply of stored energy readily available at all times that they can immediately access whenever they need to perform some kind of biological work. *Living things simply do not have time to be continuously burning fuel in order to work!* The way that life functions to create the energy it needs to perform its daily work is more analogous to *rechargeable batteries* than that of combustion engines. The energy of life is *cold chemical energy* and definitely not the hot mechanical variety seen in cars or other mechanical devices. While the utilization of energy in a living cell does create heat energy as a byproduct (you do warm up and sweat when you exercise), the primary mechanism is chemical which involves taking advantage of the energy changes that occur when individual atoms in macromolecules make or break electrical "bonds", i.e., accept or donate excess negatively charged electrons with other adjacent atoms. *For at least the past 3.5 billion years, all life-forms on earth, no matter how they obtain the energy and food they need to stay alive, have all used the exact same chemical power generator to allow them to do their actual biological work.*

With all organisms on earth, from bacteria to man, a specific type of macromolecule called ***adenosine triphosphate*** (or ***ATP*** for short) constitutes the central chemical power generator. All earth life, including plants and animals, and even extremophiles, "burn" or oxidize fuel (usually a special form of sugar known as glucose, which they have eaten or manufactured) to build ATP energy molecules. **Figure 3-7** shows a schematic diagram of how the ATP/ADP energy cycle works. The ATP molecule is a complex macromolecule made up of an adenosine diphosphate macromolecule linked or bonded with an inorganic phosphate macromolecule. A large amount of energy is required to form this chemical union between the two macromolecules. The union or bonding between these two macromolecules creates a special form of stored energy that is analogous to that contained in a rechargeable battery. When energy is needed for some kind of biological work, this union is split back into its ADP and phosphate components and the energy contained in the ATP bond is released. *This "released" energy is then used by the organism to perform whatever kind of biological work it needs to do.* Following the splitting of the ATP back into ADP and phosphate, and the releasing of energy, more glucose is burned by the organism to allow the ATP molecule to be rebuilt and put back into storage so that it will again be ready and able to provide additional energy when next needed. Each and every cell of every living organism on earth requires a huge amount of ATP to allow it to do its daily work. Every cell contains several million such ATP molecules and each and every one of them is recycled (i.e., from ATP to ADP, then back to ATP) every few minutes. Biochemists tell us that there is nothing magic about this ATP/ADP energy process, and that other equivalent biochemical systems could have been developed that would have worked just as well. Scientists believe that

the fact that this same energy system is used by all known forms of earth life is very compelling evidence that all life on earth evolved from the same common ancestor.

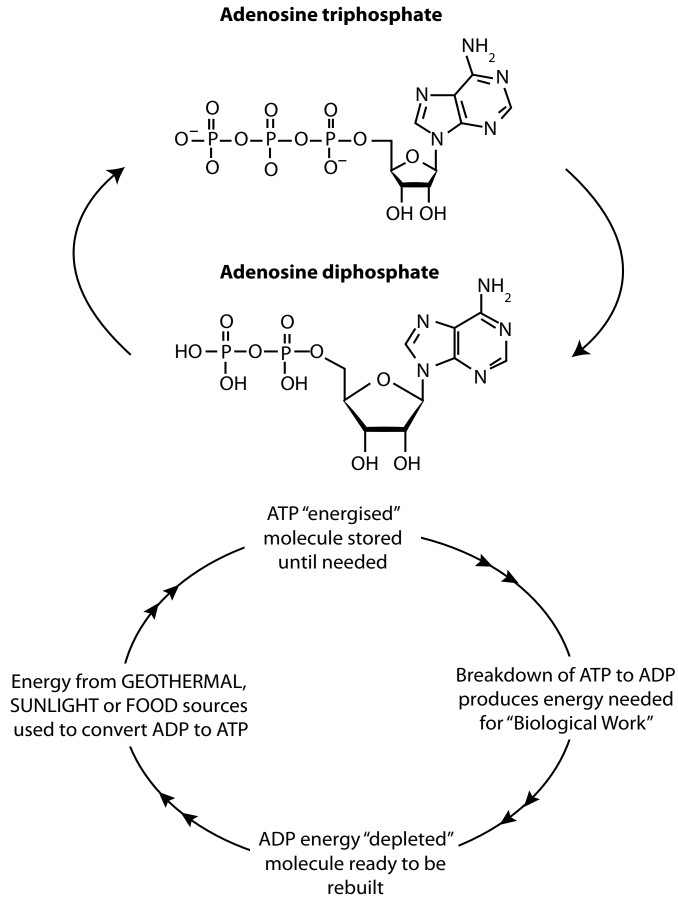

Figure 3-7 - All life-forms on earth rely on the same specially constructed energy molecules to do everything they do. These ATP molecules must be constantly built and stored away so that they will be readily available whenever the organism needs to perform some kind of biological work. Shown is an artist's drawing of how this life critical process works. (Image credit: Sarah Keeling)

Every Cell of every Living Organism Contains a Copy of an Instruction Manual which allows the Organism to Replicate Itself

In all prokaryotes (including the extremophiles), this instruction manual is free-floating along with the other life sustaining chemical components in the cytoplasm of the cell, while in eukaryotes a membrane-bound nucleus is entirely dedicated to the task of housing this life sustaining "command center". The nucleus of every eukaryote cell houses several special structures called ***chromosomes*** which are each made up of a large number of smaller ***genes***. Man has 23 pairs of chromosomes, one set inherited from dad and a second set donated by mom (**Figure 3-8**). The invention of chromosomes allowed eukaryotes to store much larger numbers of separate genes in a much smaller space than had been possible for their prokaryote predecessors to do. Prokaryotes typically use a single circular-shaped chromosome to store all their genes, while the individual chromosomes of eukaryotes consist of long linear DNA macromolecules (**Figure 3-9**). The number of genes that can be added to the circular chromosome structure of prokaryotes is limited since additional genes may cause the structure to become twisted and nonfunctional. In marked contrast, the linear chromosome structure that eukaryotes invented can easily allow additional genes to be added by simply extending the length of any given chromosome or adding additional chromosomes. In all living organisms, the genes contain the detailed information or construction plans that are used to direct the construction of the multitude of different protein "work horses" that in turn

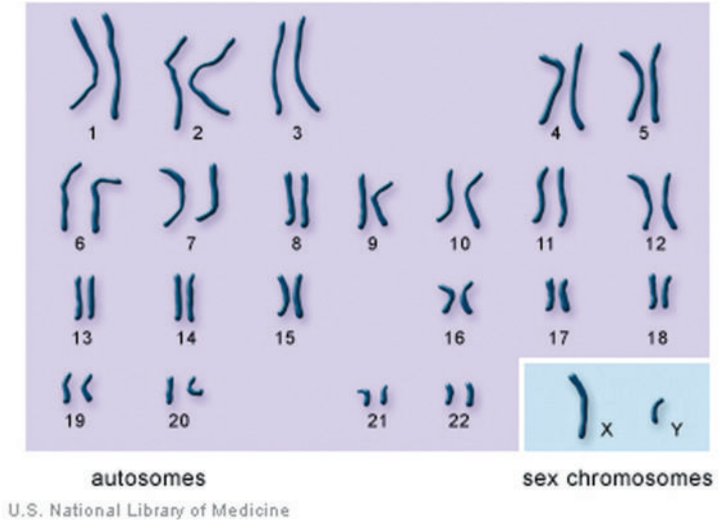

Figure 3-8 - Shows the relative sizes and shapes of each of man's 46 pairs of chromosomes. (Image credit: U.S. National Library of Medicine)

carry out the entirety of every cell's vast array of critical life sustaining functions. In fact, the concept of genetics is so centrally important and critical to life that many scientists in a kind of tongue-in-cheek manner, have even said that all of the different structural and functional components (e.g., macromolecules, tissues, organs, chemical systems and factories, etc.) that constitute the entirety of every living organism are nothing more than the ***"genes' way of perpetuating themselves"***. This concept of the extreme supremacy of the gene was probably at least a motivating factor for the members of the science panel of the Astrobiology Institute of the National Aeronautics and Space Administration (NASA) when they suggested that life should be defined as ***any chemical system that undergoes evolution***. The breaking of the genetic code by Drs. James Watson and Francis Crick in 1953 completely changed both the medical and the basic life sciences. Suddenly, we had, or were well on our way to obtaining, the detailed set of instructions or operator's manual that could explain the "hows" and even "whys" of the complicated but vague concept of "*evolution and the survival of the fittest*" first espoused by Charles Darwin in his landmark 1859 publication. Evolution, rather than being a theory, was now promoted as close as possible to the level of a law of nature as conservative scientists could ever allow. While many fundamentalist religious sects still opposed it, Pope John Paul II, in 1996, issued his opinion that evolution was not contrary to the traditional beliefs of the Catholic Church.

The author will now attempt to convey to the reader the fascinating story of how every

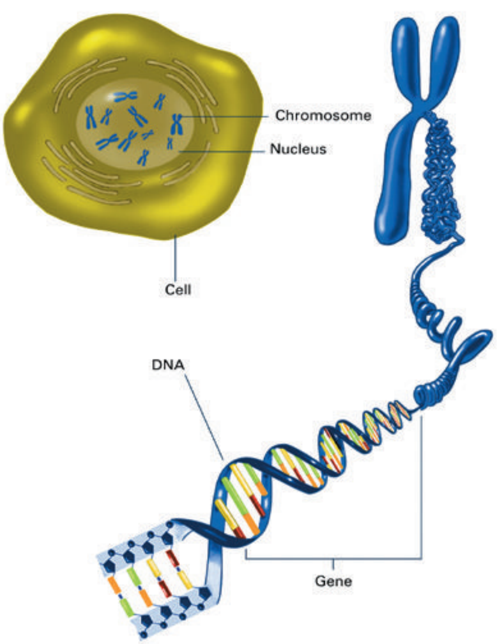

Figure 3-9 - Shows how each individual chromosome is composed of an extremely long and continuous double helix DNA macromolecule. (Image Credit: National Institute of General Medical Science)

creature on earth, from bacteria, to giant redwood trees, to man, uses the same identical genetic construction plan to do everything they do. The absolute "mother of all macromolecules" that contains absolutely all of the genetic information needed for this task is the gigantic ***Deoxyribonucleic Acid*** macromolecule, frequently referred to as the ***DNA*** molecule for short. If we were able to take a high resolution photograph (using the most powerful microscope on earth) of a typical gigantic DNA macromolecule from any sample of three individual earth life-forms, e.g., a bacterium, a limb from a red wood tree, or a cotton swab from the inner cheek of the author or reader, we would not be able to tell them apart. With respect to the three primary life functions related to growth, replication, and evolution, all forms of life on earth share the same genetic master plan, construct the same genes from the same kinds of atoms and molecules, and use the same construction tools to build and unleash into the cytoplasm of their cells the vast armies of super-molecules and chemical constituents needed to allow life to maintain and perpetuate itself. Advanced species may and have developed whole new cadres of complex biological processes that go far beyond the basic (elementary) processes that are shared by all life on earth but even these advanced features must conform to the same genetic and biological principles or rules shared by us all.

In the last 20 or 30 years, exciting scientific research emerging from laboratories all over the world has attracted the attention of the news and entertainment medias to such an extent that such terms as *DNA* and *double helix* have become virtual icons that are familiar to virtually everyone, but understood by very few. Inside the cell nucleus of every eukaryote life-form (and inside the cytoplasm of every prokaryote cell), we find a collection of what medical artists have depicted as funny-looking carpenters' ladders that appear to be the survivor of a recent tornado, since they appear to be badly twisted (ergo, look like a double helix). **Figure 3-10** shows an example of the manner in which DNA macromolecules are typically depicted by medical artists. If one were able to view a DNA macromolecule under a special microscope, all that could be seen would be a complex jumble of totally unfamiliar objects that made absolutely no sense.[2] Therefore, in defense of medical artists, it must be said that biological structures as complex as DNA macromolecules must be drastically simplified in order to allow us to make any sense of what they are and what they do. Based on our analogy between the DNA double helix structure and a carpenter's ladder we can consider the two parallel *backbones* of the DNA molecule structure (shown in Figure 3-10) as being analogous to the two parallel side posts of a carpenter's

[2]Much of the so-called microscopic world is totally invisible to the human eye, even when using the most powerful microscopes on earth. While small biological entities such as bacteria, nerves or other kinds of human cells, etc., are invisible to the naked eye, we can easily see them with a microscope. However, this is not true for the atoms or molecules that these entities are made of. Atoms and molecules (including even the gigantic DNA macromolecules) are so small that no microscope, however powerful, would allow us to see them. This is not due to the limitations of microscopes but rather to the biological limitations of our eyeballs which lack sufficient resolution to allow such small things to be seen. Atoms and their building blocks (e.g., protons, neutrons, electrons) are themselves much smaller than the basic particles of light (i.e., light photons) and would, therefore, not be visible to our eyes no matter how much we might try to magnify their images.

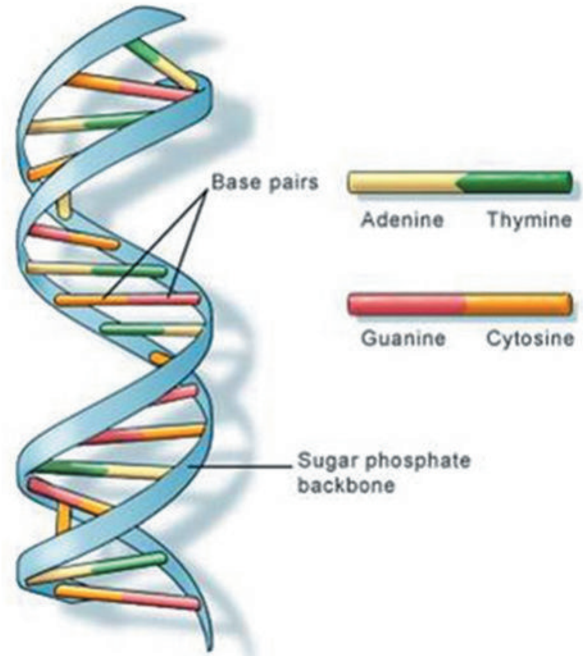

Figure 3-10 - Artist's drawing of the basic structure of the complex DNA macromolecule. (Image credit: U.S. National Library of Medicine)

ladder. In reality, the two backbones of DNA, instead of being made of wood or aluminum, are made up of continual chains of complex macromolecules (each made of a five-carbon sugar attached to phosphate). Again, using the ladder analogy, the complex macromolecules that biochemists refer to as ***nucleotides*** or simply ***bases*** are the equivalent of the steps of the ladder ("rungs") that connect the two backbones. However, unlike the steps of a ladder that are continuous from one side of the ladder to the other, the bases or nucleotides only extend approximately half-way to the midpoint between the two backbones.

All DNA macromolecules, in all living organisms, contain only four different kinds of bases. As described earlier, all proteins (i.e., giant macromolecules which may contain anywhere from a few thousand to perhaps 50,000 or more individual atoms) are composed of long strings of connected amino acids (Remember, an amino acid is one of the 50 or so basic building blocks of life each of which contain 30 or fewer atoms). The long strings of amino acids in typical proteins are actually coiled or folded up into a ball-like structure (**Figure 3-11**). The unique functional differences between different proteins (i.e., what specific jobs enzymes and other specialized proteins perform) are derived by differences in the sequential order of the different amino acids and also by the final complex shape of the rolled up "ball". It is the sequence of the four different kinds of bases along the long DNA strand that determines the order in which the building blocks of different proteins

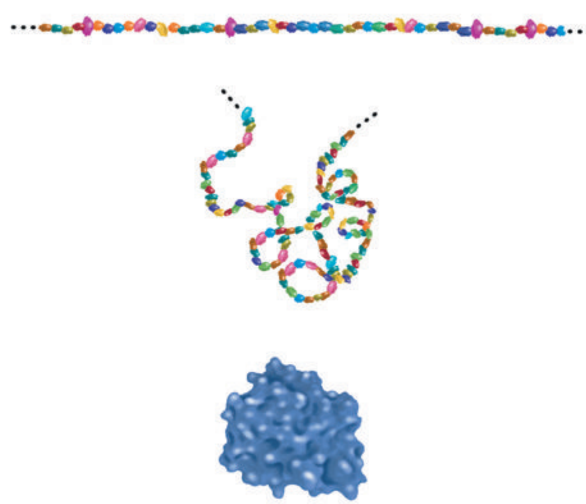

Figure 3-11 – Proteins are composed of long chains of amino acid macromolecules which are formed into tight compacted balls in order to perform their functions. (Image credit: NIGMS)

are linked together. *Thus, the information needed to line up the different amino acids in the correct order to build specific proteins is contained in the sequential order of the four different types of bases on the DNA macromolecule.* Whereas the blueprint for the construction of specific proteins is housed in the DNA strands inside the cell nucleus, the "factories" where this construction is performed is located in the cytoplasm of the cell in a special organelle called a ***Ribosome***. In what follows, I will outline the different steps that are involved in translating this *inborn blueprint plan* into the *final product*, the actual protein or enzyme needed to perform a particular biological task.

The four different bases contained in the DNA strands inside the nucleus are each unique, biochemically. Biochemists have labeled them as ***adenine*** (labeled as "***A***" for short), ***guanine*** ("***G***"), ***cytosine*** ("***C***"), and ***thymine*** ("***T***"). Each of the four bases are not only chemically unique they are also *structurally* unique. As mentioned earlier, each of the two backbones of the DNA macromolecule contains an extremely large number of evenly spaced bases. At any given point along the DNA strand a base exists on one backbone that must connect or link up with another base that is located ("across the aisle", so-to-speak) on the other backbone. The four bases differ with respect to their lengths and also, surprisingly, with respect to the physical shape of the end or surface region where one base has to connect to the other base. **T** can only pair with **A**, and **C** can only pair with **G**. The **A** macromolecule is physically longer than **T** and **G** is longer than **C**. In order to keep the space between the two backbones constant throughout the length of the DNA strand, long bases can only pair with short bases. In order for individual bases to pair up with each other, the surfaces where **A** and **T** connect together have complimentary shapes, not unlike a lock and key format (or that of a jigsaw puzzle), that will allow only these two bases to link. The **G** and **C** pair has a different lock and key format than **A** and **T** for making this connection. (In addition to this "jigsaw puzzle locking thing", individual pairs of bases also have a weak electrical bond that also assists in holding them together)

It is the differences in the sequential ordering of the four different bases that makes up the ***genetic code***. It has been determined that the smallest functional unit or ***word*** that that can be read with this code involves three bases in a row. Therefore, three bases code for a single amino acid. Since there are four bases, the total number of individual *words* in the genetic code is 64 (i.e., $4^3 = 4 \times 4 \times 4 = 64$). Since all proteins are built using combinations from the same pool of 20 amino acids, the genetic code contains a considerable amount of redundancy. Only two of the three bases in a *word* are needed to code for the same amino acid. Thus, the four base combinations of **TGA**, **TGG**, **TGC**, and **TGT** would all code for the same amino acid. Since various types of proteins are far and away the most common complex macromolecules that need to be built to sustain all life on earth, this redundancy probably adds a bit of a safety net to ensure the accuracy of this process.

The gigantic DNA macromolecules located inside the cell nucleus (as well as those located in the cytoplasm of prokaryote single-cellular life-forms) perform two major functions. The first is to replicate itself as a normal part of the normal growth and cell division process. The

Figure 3-12 - An artist's view of how each individual DNA macromolecule is split into two exact copies in preparation for the normal division of the parent cell into two daughter cells. (Image credit: NIGMS)

DNA copying process itself (**Figure 3-12**) is quite complex, and involves a number of different steps and requires the assistance of more than a dozen different specialized enzymes. Some enzymes assist in unwinding the double helix and breaking the connections between the base pairs; other enzymes gather newly constructed bases and make sure they get accurately linked to their new partners. Finally, other enzymes participate in adding new backbones and rewinding the two new duplicate double helix macromolecules.

The second major task performed by the DNA macromolecules is to make sure the information contained in the gigantic DNA macromolecules make their way to the cytoplasm of the cell where the actual construction of new proteins takes place. This job belongs to a second form of gigantic macromolecule known as the ***RNA*** macromolecule (or the ***Ribonucleic Acid*** molecule for those readers who desire ammunition for their trivial pursuit games). Rather than being a double helix type macromolecule, RNA is a single stranded version of its DNA counterpart (i.e., half of a ladder), and contains only one long backbone strand. Like DNA, this macromolecule also contains a series of four different bases attached to its backbone. While DNA and RNA both use the bases adenine, guanine, and cytosine, RNA has substituted the base ***uracil*** for DNA's thymine. In all living organisms, the RNA macromolecule functions as a very "busy person". In fact, there is not just one RNA macromolecule, but a whole "family" of related macromolecules (which scientists label collectively as "messenger" RNA or mRNA for short). While several different types of mRNA collectively participate in the task of building new proteins, we will, for the fun of it refer to them in the following discussion as "first cousins". The cousins team up to perform all the critical steps that are required to accurately translate the information from the DNA chain (related to the specific base sequence) to the structural sequence of amino acids in newly constructed protein macromolecules. One of the mRNA cousins travels to the cell nucleus and unzips a section of the DNA double helix that contains all the bases of one complete gene. A second team member then places itself inside the separated section of the double helix and adds copies of the original series of bases from the DNA strand onto its own backbone. This mRNA cousin, which now has a complete copy of the information (i.e., the sequence of bases for one specific gene) from the DNA macromolecule "on its back" then leaves the nucleus and goes to a special organelle (the ribosome) located inside the cell's cytoplasm. A third

mRNA cousin then goes out into the cell's cytoplasm and gathers a handful (actually, more like a truckload) of different amino acids that are matches to the copies of the DNA bases that her cousin just brought to the ribosome. These amino acids are then brought to the ribosome where yet another of the cousins links them together into a protein chain. While the process of building new proteins is difficult to describe, it is apparently even more difficult to depict in the form of a diagram or artistic illustration. **Figure 3-13** shows one brave medical illustrator's excellent attempt to do this.

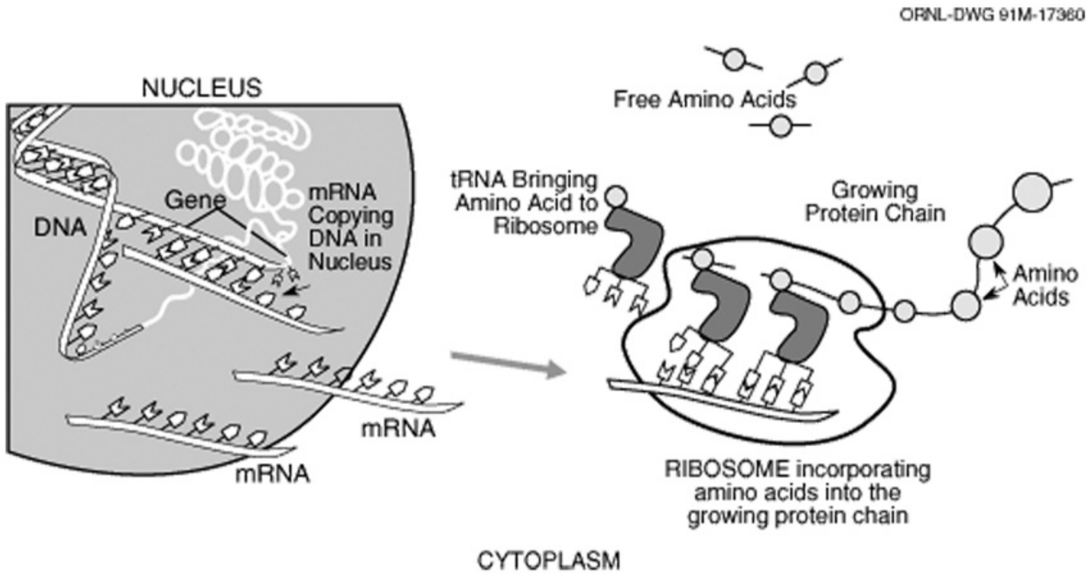

Figure 3-13 - The specific sequence of the four types of DNA bases for any given gene determines the sequence of amino acids that will be needed to build a specific protein macromolecule. Shown is an artist's simplified illustration of how RNA copies genetic information from the DNA macromolecules in the cell nucleus and then carries this "copied information" to the ribosomes where it is used to direct the gathering of amino acids from the cell's cytoplasm and linking them together to form a new protein macromolecule. (Image credit: Biological and Environmental Research Information System at Oak Ridge National Laboratory)

Finally, before discussing the more global issue of how evolution works in the real world, the author would like to again review some important points presented above. First, it is important to note that one individual gene codes for one individual protein, and that different genes code for different proteins. The specific sequence of the nucleotides along the strand of the DNA macromolecule codes for the specific sequence of amino acids along the protein macromolecule. In fact, both genes and proteins are extremely long strands of huge numbers of their respective basic building blocks (nucleotide bases and amino acids, respectively). The average individual gene contains close to 1500 base-pairs linked together in a long chain, although the individual differences among genes is very large (genes may contain as few as several hundred to as many as 2 million base-pairs). Since a series of three different bases is required to code for one amino acid, the average protein macromolecule consists of 500 amino

acids (again, with large variability) joined together in a chain. Finally, although smaller in many lower animal and plant species, the individual chromosomes in man contain anywhere from approximately 100 to 1000 genes, and the human genome (i.e., the total number of different genes that humans possess) is estimated to be somewhere between 20,000 and 25,000. It is very interesting that, if we took one chromosome and stretched it out end-to-end (see Figure 3-9), it might measure as long as six feet in length (if it were one of the longer chromosomes). Fortunately, as can also be seen in Figure 3-9, the chromosomes in man and other eukaryote life-forms are tightly coiled up to save space inside the extremely small nucleus.

All Life must Adjust to Short Term Changes in the External Environment plus Undergo Biological Evolution in Response to Long Term Alterations

The concept that life gradually adapts or "evolves" in response to environmental changes is not a new idea in the history of science. It made its appearance early (well before the birth of Christ) in Greek philosophy, and was advocated by a fairly large number of respected Greek philosophers including, among others, Anaximander, Empedacles, and Epicurius. These influential thinkers of their day believed that life probably first originated in the oceans and later evolved into more complex forms, and also that groups of animals that were poorly adapted to their environments would probably perish and become extinct. Sometime around 350 B.C., however, the influential Greek philosopher Aristotle made his profound statement that different life-forms were fixed and independent of each other and do not undergo any form of evolutionary changes. Aristotle's opinion was adopted by the Catholic Church and became the dominant theme that would rule the civilized world for at least the next 2000 years. Even today, this viewpoint is still supported by a substantial proportion of the world's population. However, by the end of the 16th century the discovery of growing numbers and varieties of fossilized remains of past life-forms began to suggest to some scientists that the fossils might actually be the ancestors of many of today's living species. In the early 1800s a French paleontologist named Jean Batiste Lamarck opened the door to the modern era of evolutionary theory when he speculated that the similarities between the fossil record and the morphologies of many living species strongly pointed to some kind of evolutionary change over time. Lamarck was the first scientist to endorse the modern idea that life-forms that evolve by gradually adapting to their environments are the ones that are most likely to survive and prosper. Unfortunately, Lamarck believed that this adaptation involved only those characteristics that individual organisms acquired during their lifetimes. Therefore, the strong muscles developed by farmers working in the field would be passed along to their children. Likewise, the reason giraffes have such long necks is that those individuals who spent more time stretching their necks to get at the leaves on the higher branches of trees developed slightly longer necks which were subsequently inherited by their offspring.

In 1859, an English naturalist named Charles Darwin published his book entitled ***The Origin of Species*** which completely changed the course of the life sciences.[3] Although his theory of evolution and natural selection has turned out to be amazingly accurate, Charles Darwin knew nothing of genes, DNA, RNA, mutations, or any of the biochemical underpinnings that would almost a century later provide the scientific proof for his remarkable brainstorm. Darwin was a keen observer, a compulsive data collector (and sketch artist as well), and a staunch rebel when it came to accepting the theological dogma of his time. Being human (and also having trained in his youth to be a theologian), Darwin was a bit nervous and uneasy about the fact that his theory did conflict with official church opinion (which may have been the reason he procrastinated for so long before publishing his book), but did not let this deter his trust in his own observations. Unlike most scientists, Darwin was strictly an observer of nature - he never did experiments in laboratories. At age 22, he signed on as a "naturalist" on the HMS Beagle, an English ship that would, for five years, explore and map the coast of South America and nearby islands, including the famous Galapagos Islands. The Galapagos Islands are a group of islands that are isolated from each other which has allowed the independent evolution of a large variety of different species of plants and animals (including birds, turtles, lizards, etc.). Darwin, with nothing but pencil, writing pad, small telescope, and a large bag to store samples, collected an astounding amount of evidence that provided strong support for his growing ideas related to the evolution of species.

The Darwin-Wallace theory of evolution is based on two major observations related to the way in which life-forms change over time. The *first* observation relates to the fact that most of the time, and in most environments, the breeding and reproduction of individual members of a specific animal (or plant) *population* (defined as all of the individuals of the same inter-breeding species who live together in one geographic location) occurs at a faster rate than the local environmental resources can support. More offspring are produced than can be adequately fed or sheltered. This results in *competition* among the individual members of the population. Thus, the population members are forced into a *struggle for survival*. The *second* observation relates to the fact that, in all animal or plant species, the individual members of the population exhibit differences among themselves with respect to specific morphological and functional characteristics. Some are larger, stronger, can run faster, can see or hear better, have longer fur (or shorter fur), and so on. Almost all of these characteristics are inherited from their parents. A very small number (i.e., as we will very soon see, the ***mutations***), however, are not. Whether

[3]While Darwin was the first scientist to publish the theory of evolution in book format, he had a respected colleague and friend named Alfred Russel Wallace who had been developing a virtually identical theory for quite some time. As history has it, Wallace made a major invited presentation to a gathering of scientists in London, England on July 1, 1858 in which he presented the details of his own theory. Hearing that Wallace was close to publishing his theory, Darwin got busy and finished his book manuscript (which he had been working on for years but procrastinating on submitting for publication) and had it published before Wallace was able to submit his own manuscript. Although Darwin published his book first, Wallace is today considered by most scientists to be the **co-developer** of the theory of evolution.

inherited or not, some of these characteristics will give some individual members of the group an advantage over the others in terms of being able to survive long enough to breed and pass their "lucky genes" on to their own offspring. Other members of the group may have inherited characteristics that place them at a disadvantage in this survival of the fittest saga. Therefore, in the 1850s, when Darwin and Wallace were tackling the daunting issue of the evolution of life, they could only address the question of "what" happened; the question of the "how" would take another 100 years or so to begin to be resolved.

In 1953, the question of the "how" of this greatest of all biological mystery stories was finally solved. James Watson and Francis Crick finally *broke the genetic code*! Of course, the author must emphasize that there were numerous other individual scientists in the 100 year time span between Darwin/Wallace and Watson/Crick that slaved away in laboratories all over the world who paved the way for Watson and Crick. Anyone who thinks science and science research is a tedious and extremely boring way to live should read Watson's excellent book entitled ***The Double Helix: A Personal Account of the Discovery of the Structure of DNA*** (New York: Atheneum Press, 1968). Watson wrote this short book for general readers. It reads like a humorous mystery novel, and even recounts the exciting competition between the Watson/Crick team in England and Linus Pauling's group in California as they went head-to-head to be first in breaking the genetic code.

At its very essence, the primary goal of all science is to *"explain"* things that happen in the natural world. In science, an explanation is a description of all the different *"causes"* that come together to produce a specific *"effect"*. However, the first stage of any new science is to totally and completely describe the details of *"what happens"* with respect to some phenomenon that we do not yet understand. This is what Darwin and Wallace at first did. They observed many different animal (and plant) species and described everything they could about them with respect to how they lived, where they lived, what they ate, how their bodies were built. Darwin, as we know, also focused on what kinds of seeds the Galapagos Island finches ate, and what kind of beaks they had for breaking the seeds. Darwin also studied the effects that controlled breeding (by animal breeders and farmers) had on rapidly accelerating the apparent rate of "evolutionary" changes in domesticated animals. Darwin's descriptive studies provided the critical *"what happens"* information that was needed for the new science of *Biological Evolution*. The second stage of any new science is to identify and isolate (separate) the *causes* and *effects* with respect to the phenomena being studied. The scientist's objective is now to determine *"what causes what" and "what are the effects of different causes"*. The detailed explanation or elucidation of the causes and effects related to biological evolution is where the 20th century scientists, including Watson, Crick, Pauling, Woese and many others enter the picture. In the remainder of this chapter, I will provide a brief simplified overview of the genetic mechanisms that underlie the phenomenon of biological evolution.

As described above, we now know that the basic unit (i.e., the smallest indivisible entity) for the inheritance of biological traits is specific segments of the long DNA macromolecule. Each

individual segment or individual gene consists of long chains or strings of individual nucleotides or bases. Man has between 20,000 and 25,000 separate genes. Every cell of our body contains a complete set of these individual genes packaged in the 23 pairs of chromosomes housed in the nucleus of each cell. However, it is important to note that, at least in multi-cellular life-forms not all of the genes in every cell are *active* (or "online" to use computer jargon). Only those genes that are needed for the specialized functions of the particular tissue (or organ system) that the cell is a member are functional - other genes are "turned off". It seems it was easier for nature to simply go ahead and place a complete genome inside every cell than it was to try to place limited sets of genes into the 200 or more different types of cells that man possesses. The determination of which genes are turned on or off at any time inside any individual cell is determined by a special form of protein called a *regulator protein*.

Now, how do "inheritable traits" change? The general term that scientists use to describe the occurrence of any new gene that has the potential to be passed along to its owner's offspring is a ***gene mutation***. There are many different types of causes for individual gene mutations. In the course of the replication of genetic material during growth or normal cell division, copying mistakes can occur. The wrong bases can be placed in the wrong locations along the DNA strand or extra bases can be inserted or other bases can be inadvertently left out. Fortunately, these kinds of errors are extremely rare since, at the time of the actual copying, a large number of specialized enzymes (again, of course, proteins) are present in the nucleus whose job it is to double check the copying process and correct any errors that might occur. However, in spite of this backup safety system, copying errors do sometimes occur. However, for purposes of passing along inheritable traits, the only copying errors we need to be concerned with are the ones that take place in the organism's ***gamete cells*** (i.e., in the case of man and other animals, the sperm cells in the testes, or the egg cells in the ovary). Copying errors in other body cells may produce other undesirable effects such as unsightly moles, or skin cancer, etc., but these changes would not be passed along to the offspring. ***It is important to note that, when we talk about genetic mutations, the vast majority of everyday mutations, <u>whether they occur in body cells or gamete cells</u>, are totally benign, i.e., have no observable effects on the individual organism's lifestyle, or mortality, etc.*** When genetic mutations occur in gamete cells, while typically benign, they do have the potential to be passed along to and alter the future offspring's lifestyle, mortality, etc. In addition to simple copying errors, mutations can have a variety of other causes. Exposure to toxic chemicals from the environment, or in the diet, can produce mutations. Also, exposure to too much sunlight or radiation (x-rays, gamma rays associated with nuclear materials, etc.) can produce mutations. Once again, many organisms, including man, have evolved specialized enzymes that can frequently "make repairs" to such damaged genes. In recent years it has been discovered that certain types of mutations may even be *caused* by other genes that some unfortunate individuals may inherit from their parents.

When genetic mutations that occur in the gametes are passed on to the offspring, whether they have any effect on the individual organism's lifestyle will be determined by the specific

internal or external environment in which the organism lives. If the altered gene is a "good gene" it may enhance its owner's health and other inherent biological functions in such a way that it will live long enough to breed and pass this new gene to the next generation. If it is a "bad gene" it may make the individual organism die prematurely or not be healthy enough to later court and breed. More likely than not, the altered gene is neither good nor bad and has no effect on the organism's current lifestyle, but might do so in the future. The altered gene could, therefore, produce biological changes that could either immediately facilitate or impede survival in their current external environment, or, alternately, be available to do so when, in the future, the environment does change. An altered gene that resulted in long hair would not be good if its owner lives in a warmer climate; likewise, one that caused baldness or short hair would be bad news to any unfortunate critter that might live in a colder climate. Therefore, the bottom line of Darwin's concept of *evolution and survival of the fittest* is simply the question of whether an inherited mutated gene facilitates an individual organism's ability to produce more viable offspring than their competitors who do not have the new altered gene. Over time, as the numbers of group members with the new altered gene begin to outnumber those without the new gene, the new gene becomes a "normal" gene for the gene pool of the population.

As we will discuss in the next chapter, the external environment in which a specific population of organisms lives is frequently a major determinant of whether the occurrence of any given genetic mutation will result in evolutionary change. Slower environmental alterations are usually better in terms of permitting evolutionary change than are sudden alterations. Any new genetic mutation that, for example, might allow a given individual to adjust to a changing environmental condition (e.g., climate getting warmer, colder, wetter, dryer, etc.) will require some time (perhaps tens to hundreds of generations, or longer) to be able to spread throughout the population. If the climate change occurs suddenly, the species may perish before it has time to incorporate the new protective gene into its genetic pool. In the next chapter, I will describe several major extinction events in the history of life on earth in which dramatic climate changes occurred so fast that whole populations were virtually wiped out before genetic evolutionary changes had time to kick in to protect them. Also, it appears that evolutionary change in a population can oftentimes be speeded up or enhanced when a small segment of a larger population becomes isolated. The smaller size of the isolated group allows the mutated gene to be dispersed to the majority of the group's membership in fewer generations. The rapid emergence of new species of organisms appears to be facilitated by any form of isolation event, be it climatic or geographical. Likewise, smaller isolated population groups seem to be more susceptible than larger populations to environmentally induced extinction events since their smaller numbers provide less of a chance for protective genes to pop up by chance than would be the case for the larger population.

CHAPTER IV

HOW LIFE AND EARTH CO-EVOLVED TO PRODUCE A LIFE-FRIENDLY BIOSPHERE

In this chapter, the author will present a historical overview of how life evolved on our planet. This discussion will focus not just on evolution of specific animal and plant species but also on the evolution of the earth itself. The last half of the 20th century not only saw tremendous breakthroughs in our knowledge of the life sciences, but the earth scientists also were awakened by a surge of startling new discoveries that totally changed their views of planetary evolution. It has now become quite apparent that in order to truly understand the origin and evolution of life, we must also completely understand the evolution of the environment in which life occurs. The two phenomena are totally intertwined -- the earth determined how life evolved and, in turn, Life influenced how the earth evolved. Before life, the earth was little more than a hot molten ball of rock. Now, a little over four billion years later, it has reached a stage that a few scientists have gone so far as to describe (in a somewhat tongue-in-cheek manner) as being a "living, breathing, biosphere". The author must, however, emphasize that the use of the term co-evolution in this context does not mean that both the earth and life underwent evolutionary processes in the biological sense. Life evolves by a process of random gene mutation combined with survival of the fittest in response to environmental changes, while the earth evolves primarily in response to the natural laws of physics and chemistry that are associated with extremely slow changes on our planet (and, presumably, on any other similar planet in the universe) that occur over incredibly long periods of time. However, in the present chapter, I will emphasize another real sense in which the earth evolves, and that is in *direct response to what living creatures do to it*.

Scientists' Mind Boggling Concept of DEEP TIME

In Chapter 2, when describing the size and extent of the known universe, I forewarned the reader that, in the present book, we would frequently be forced to use completely foreign or unfamiliar terminology or language in trying to describe strange phenomena that were totally

mind-boggling to most of us earth-bound types. In the present chapter, I will, once again, need to ask the reader to check his/her common sense at the door and bear with my attempts to explain yet another difficult concept which has been thrust upon us by our scientific friends. This new concept is ***deep time***. Deep time is a descriptive term that paleontologists and earth scientists use to refer to the incredible lengths of the time intervals that are necessary whenever describing events that occurred millions or billions of years ago (or, alternately, will happen millions or billions of years in the future). Just as none of us, scientist or nonscientist, can ever totally comprehend the meaning of *light years* as a distance measurement, we cannot be expected to fathom events that occurred millions or billions of years ago. If I walked up to a stranger on the street and told them that, 10 years from now, our sun would expand to an extremely large size and burn up all life on earth, they might, if they believed me, get upset (or call a policeman to have me hauled away). If, however, I told them that science now assures us that, while this catastrophic event will actually happen, it will not happen for probably another five billion years, they would probably not even blink an eye. If I further told this person that every one of the living cells in his or her body as well as my body (plus all other critters alive on earth today) had directly descended in a continuous non-stop manner from a single living cell that swam around in the oceans almost four billion years ago, they would probably laugh at me and walk away (or ask me where the camera is). Mankind's mental image of time is almost totally linked to the pace of our own very brief life spans. Psychologists tell us that the majority of people cannot fathom or comprehend the temporal aspects of events that occurred more than just a few hundred years ago. Even our most experienced scientists find it extremely difficult to fathom and understand the unbelievably slow pace of biological evolution, which makes it even harder to communicate to the nonscientific public what is going on.

Before we begin reviewing the major biological and geological events that occurred during the past 4.5 billion year history of the earth, I will attempt to assist the reader (and myself) in obtaining a better mental image or "big picture" of the enormity of the time factors that are involved in this extremely long history. Two different "time analogies" related to the incredibly slow pace of evolution will be presented.

TIME ANALOGY 1 - CONVERTING THE 4.5 BILLION YEAR HISTORY OF EARTH INTO A SINGLE 24-HOUR DAY

With this analogy, the earth would have been fully formed (i.e., the end of the accretion process which actually occurred about 4.5 bya) at midnight, but that ancient single-celled ancestor of ours (that lived 3.8 bya), would not evolve and start doing its swimming thing until four hours later at 4 a.m. Things then would not change very much (life would continue being single-celled and microscopic, i.e., too small to be seen with the naked eye) until the following evening at about 7 p.m. when the first macroscopic (visible to the naked eye) multi-cellular

life-forms would make their debut on earth. After that, life would seem to virtually "explode" in terms of size, complexity, and diversity with all sorts of new multi-celled organisms evolving right and left until, just before 11 p.m. (i.e., a tad more than one hour before the end of our 24 hour day), the dinosaurs would make their appearance. And then, with a full minute and a half before midnight, the first cave dwelling humans would arrive, and with less *than one second left before the stroke of midnight*, human civilization would get started.

TIME ANALOGY 2 - CONVERTING THE 13.7 BILLION YEAR HISTORY OF THE UNIVERSE AND EARTH INTO A SINGLE 364 DAY CALENDAR YEAR

Early in his remarkable career, the astronomer Carl Sagan compared this frustrating deep time concept to that of a single 12-month calendar period. In an excellent 1977 popular science book entitled ***The Dragons of Eden*** (New York: Random House), Sagan presented his now well known ***Cosmic Calendar*** in which he translated what was then thought to be a 15 billion year history (which is now believed to be closer to 13.7 billion years) of the universe and earth into one 364 day earth year. The unique feature of Sagan's calendar analogy was that he separated the single year into three separate temporal periods or stages, which reflected the absolutely incredible magnitude of the increases in the pace of the evolutionary events that transpired as the year progressed from January through December. It is this extreme "change of pace" phenomenon that makes deep time virtually impossible to comprehend.

Sagan's Cosmic Calendar breaks the year into ***three time intervals*** beginning with the ***first 11 months of the year***, i.e., January 1 to November 30 (midnight), followed by the ***last month of the year***, December 1 to midnight of December 30, and finally that of the ***last day of the year***, December 31 (from midnight to midnight). During the first 11 months of the Sagan calendar year the universe was born, the earth was built, and then sometime during the month of October the first primitive single-celled life-forms arrived and began evolving at an absolutely slow snail's pace right up to the end of the second week of December. Then, thanks to the arrival worldwide of a relatively more stable and cooler climate, plus lots of oxygen in the atmosphere and sexual reproduction, life's evolutionary pace suddenly began to switch gears to an incredibly more rapid pace and new life-forms began popping up everywhere that were now definitely larger (multi-cellular and no longer microscopic), and more complex. The dinosaurs themselves arrived about a week later (on or about Christmas day) and, finally, sometime during the early morning hours of the very last day (New Year's Eve) of the Sagan calendar year man's earliest primate ancestors arrived on the scene and the stage was set for the arrival of the first modern humans a full hour and a half before the end of the Sagan year. And, then, ***with a full second left before the stroke of midnight on December 31, someone named Christopher Columbus discovered America!*** Beginning on the next page, I will present a slightly abbreviated version of Dr. Sagan's original three-part Cosmic Calendar.

Pre-December events (modified Cosmic Calendar)

Big Bang	January 1
Origin of the Milky Way galaxy	May 1
Solar system begins accreting	September 9
Formation of the Earth	September 14
Oldest earth rocks	September 20
Carbon isotope evidence of life	September 30
First fossil single-cell Prokaryotic life	October 28
First Oxygen producing bacterial fossils found	November 5
First single-cell Eukaryotic life (cells with nuclei)	November 21
Invention of sex (by microorganisms)	November 30

December events (modified Cosmic Calendar)

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1 Oxygen atmosphere begins to develop	**2**	**3**	**4**	**5**	**6**
7	**8**	**9**	**10**	**11** Glaciers cover most of world. (Snowball earth)	**12**	**13** First multi-cellular organisms
14	**15**	**16**	**17** First sponges, corals, jellyfish	**18** First oceanic plankton	**19** First fish, Atmospheric ozone layer develops	**20** First plants colonize land
21 Animals begin to colonize land	**22** First amphibians and winged insects	**23** First trees and first reptiles	**24** First dinosaurs, first mammals	**25**	**26**	**27** First birds
28 First flowers, extinction of dinosaurs	**29** Explosion of giant mammals	**30** First carnivores, primitive primates	**31** First apes, hominids, humans			

December 31 events (modified Cosmic Calendar)

First grasslands, cows, deer, horses	4:00 a.m.
Origin of common ancestor of both apes and man	10:00 a.m.
First great Apes	4:00 p.m.
First hominids	9:00 p.m.
First modern humans	10:30 p.m.
Widespread use of stone tools	11:00 p.m.
Domestication of fire	11:46 p.m.
Beginning of most recent glacial period	11:56 p.m.
Cave paintings in Europe	11:59 p.m.
Invention of agriculture	11:59:20 p.m.
First cities	11:59:35 p.m.
Invention of alphabet	11:59:50 p.m.
Development of metal (iron, bronze) tools	11:59:54 p.m.
Roman Empire; birth of Christ	11:59:56 p.m.
Discovery of America	11:59:59 p.m.

Hopefully, these two mental exercises involving "analogizing" the age of planet earth to a single day versus a single year will help the reader better comprehend the incredibly long time intervals that will now be the major focus of this chapter. I freely admit that, while these analogies are helpful in allowing me to intellectually accept this strange time concept, they do not go as far as I would like in terms of making these ideas more comprehensible. Fortunately, in order to make it easier to describe and keep track of when, and in what order, specific geologic and life events occurred in *deep time*, scientists have developed a formal system for dividing up this 4.5 billion year deep time "monster" into a number of individual shorter time periods (i.e., Eons, Eras, Periods) in which specific events are believed to have occurred. **Figure 4-1** shows an excellent example of one such *geological time scale* that astrobiologists Jeffrey Bennett, Seth Shostak, and Bruce Jakosky developed for their textbook, entitled *Life in the Universe* (see reference 21 at end of this book). This chart illustrates the different geologic time periods in which many of the environmental and evolutionary life-form events described in this chapter are thought to have occurred following the formation of planet Earth.

We will now turn our attention to the task of describing this difficult but very fascinating *deep time* saga. The general format of the present chapter will be historical in nature. The author will begin with a description of the major geological and biological events that occurred during the earliest post-bombardment years and proceed forward in time. At each successive stage or interval in this history, I will describe what major geological and biological changes

occurred with major emphasis on how the two types of changes influenced each other (ergo, our theme of the co-evolution of life and geology).

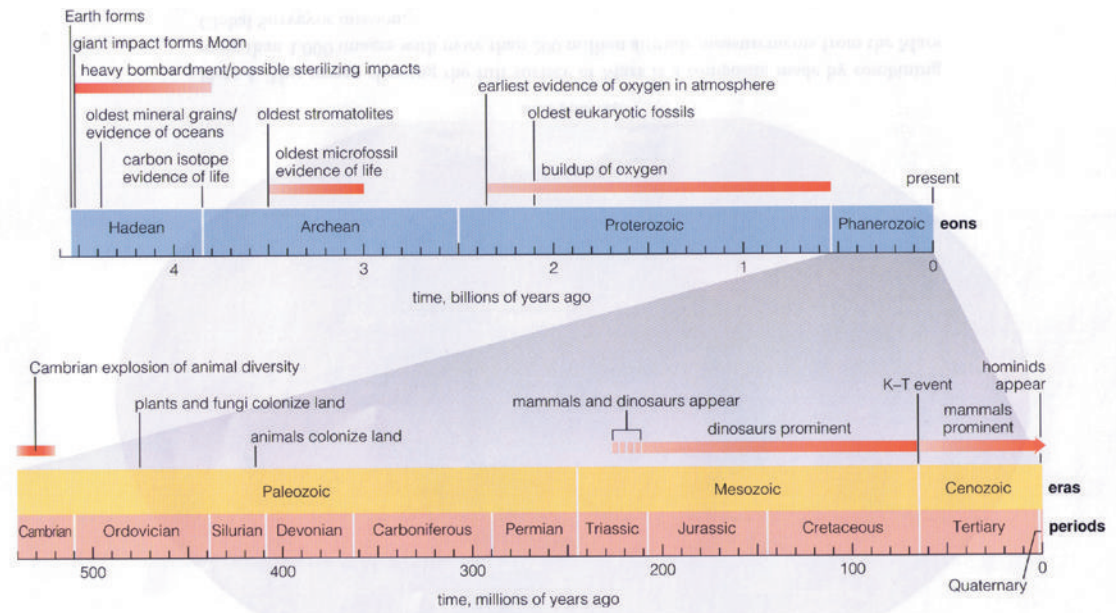

Figure 4-1 - Shows the geologic time scale of the major evolutionary events that came together to allow life to originate and develop on planet earth. (Produced with permission from J Bennett, S Shostak, & B Jakosky, Life in the Universe, Addison Wesley, 2003)

Hadean Eon Witnessed Gathering of Raw Materials Needed for Birth of Life on Earth

As described in Chapter 2, the period from approximately 4.5 bya at the end of the accretion period to 4.0 bya is known by geologists as the Hadean Eon, or the time of "hell on earth" since it was also the period of the most intense bombardment by marauding space debris left over from the accretion process. Until close to the end of the 20th century, virtually all scientists believed this time period was definitely not yet ready to support any form of life even remotely resembling life as we humans know it. At this early date, the planet still had five major strikes against it as a possible abode for life. The earth was (1) extremely hot (as a result of leftover heat from the accretion process, plus atmospheric greenhouse warming effects combined with heat generated by other sources located deep below the earth's surface); (2) had just started developing the very first oceans that had ocean floors that were seething with intense and virtually constant volcanic activity; (3) was still being seriously peppered by frequent bombardments from leftover space debris that were often severe enough to melt the surface crust and evaporate any early oceans that had managed to develop; (4) had an

atmosphere (filled with water vapor, carbon dioxide, and an assortment of other noxious or poisonous gasses delivered courtesy of the volcanoes) that was definitely not life-friendly, at least by today's standards; and (5) had virtually no stable land surfaces (the first true continents would not begin developing for almost another half billion years).

If, as many scientists now believe is probably the case, the first living organisms did finally establish a permanent foothold on earth at the beginning of the subsequent Archaen Eon sometime between 3.5 and 3.8 bya (or, possibly, even earlier), a considerable amount of prebiotic evolutionary development would possibly have had to occur during the tail end of the Hadean Eon. Thus, the first major question that now must be posed is "*How did all the critical physical and chemical materials needed to support life get here*"? Put more bluntly, how on earth did this hostile world get its act together so quickly?[1] Since liquid water is considered by virtually all scientists to be the single most critical ingredient that is needed to support life, or at least life as we know it, where did the water come from? Although not all scientists fully agree, many now believe that the first oceans were likely present by 4.0 bya, and possibly even as early as 4.2 bya. As described in chapter 2, the four inner planets (Mercury, Venus, Earth, and Mars) formed in a region of the planetary accretion disc where it was so hot that only non-volatile chemicals like metals or rocky materials were able to condense into solid matter and participate in planet formation. Because of the heat, volatile chemicals like water or methane remained in gaseous states and were blown (by the solar wind) to the outer regions of the accretion disc where, because of the much colder temperatures, they were able to condense into icy particles and help form the giant gas planets.

Most scientists now believe that the origin of the oceans was a beneficial side effect of the later stages of the accretion process as well as the heavy bombardment period. Since asteroids and comets formed in the outer colder regions of the accretion disc, both are known to contain significant quantities of water ice. Scientists estimate that these objects are actually made up of approximately 5 percent water.[2] Comets, in fact, are described as being "dirty snow balls" since they are mostly composed of large quantities of dust to gravel-sized rocky particles (or larger) packed together with icy materials. That long tail-like object of material that streams along behind comets when they approach the sun is, in fact, composed, in addition to dust, of water ice, and silicon- and carbon- based compounds (including some organic molecules) that have been melted, vaporized, and blown away by the sun's heat. Most scientists now believe

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[1]Although scientists disagree on how quickly earth became life friendly enough to support the first carbon-based life-forms, it does stretch the imagination to think that what must have been a long line of "pre-biotic" evolutionary events (i.e., the events prior to the first fully formed cell) could have been completed in just a few million years or, as some suggest, possibly a few hundred thousand years. Of course, it would have had to *successfully* happen *only once* somewhere on our relatively large planet.

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[2]Because of the fact that approximately 70% of the earth's surface is covered by water, most of us intuitively believe water is very abundant on our planet. In fact, only about .023% of the earth's mass is water (i.e., less than ¼ of 1 percent). Thus, in spite of the fact that the average depth of the oceans is 2.3 miles, the relative water content of our "water world" is quite small.

that the constant pounding of the earth's surface by planetesimals , asteroids, and comets during the later stages of the accretion process plus the Hadean or heavy bombardment period was the mechanism by which most of the necessary water was delivered to fill the oceans. Small amounts of water continue to be delivered even today by small meteors (i.e. the so-called "shooting stars") that continually enter our atmosphere. During the earlier more violent stages of the accretion process, when the earth was largely in a molten state because of the intense heat generated by the bombardments, large numbers of objects from the outer cooler regions of the solar system, which contained water, would have frequently wandered into the neighborhood of the inner planets and collided with the growing earth (as well as Mercury, Venus, and Mars). These water-carrying visitors would probably have become trapped deep below the earth's surface. This water (along with certain gases, e.g., carbon dioxide, carbon monoxide, sulfur dioxide, hydrogen sulfide, etc.) would have later been added to the surface as a result of outgassing associated with severe volcanic activity that occurred almost constantly during the entire Hadean Eon.

Now, what about the composition of the early atmosphere? While there continues to be considerable disagreement among scientists on this issue, virtually everyone agrees it was drastically different from what it is today. Because of the continuing reign of terror from the skies (bombardments), which sometimes caused the oceans to evaporate entirely, plus the intense heat of the planets crust, we can assume that the early atmosphere contained considerable amounts of water vapor. Also, because of the frequent surface melting, vaporized rocky materials (silicates) were probably also present, as were large amounts of carbon dioxide, plus sulfur-bearing and possibly small amounts of methane and ammonia gases. Any life-forms that developed in this early time would have not only have had to like it hot, but also to be of the *anaerobic* lifestyle persuasion (i.e., not needing oxygen to live) in order to survive.

Now that we know where the water needed for life came from, the next major question that needs to be addressed is what was the source of all the chemical stuff that would be needed to build life? ***Most scientists are amazed by the fact that the chemicals that had been used to build our planet are very different from those that would have been needed to build life!*** Ninety six percent of the chemical composition of all life consists largely of the "big four" elements hydrogen, carbon, oxygen, and nitrogen. The earth, in contrast, is itself made up largely of hydrogen, oxygen, silicon, aluminum, magnesium, and iron. Other than hydrogen (which is virtually everywhere), oxygen is the only atomic element that is a relatively common ingredient in the chemical makeup of both earth and life. Thus, life and earth are made up of different things. In fact, the composition of life more closely matches that of the stars than that of the earth. Living things appear to be made up more of "star dust" than "earth dust".

Prior to 1950, many scientists believed the composition of earth's early atmosphere was more like the present day atmospheres of the gas giant planets in containing considerable amounts of molecular compounds made up of the elements hydrogen, carbon, and nitrogen such as ammonia (NH_3 which contains one nitrogen atom electrically bonded to three hydrogen atoms)

and methane (CH_4 with one carbon atom bonded to four hydrogen atoms). If this were the case, these scientists thought it might be possible to take some kind of energy source, such as lightening (from thunderstorms), and force these hydrogen and carbon rich molecules to rearrange their electrical bonding relationships with each other and other elements to create the critical building blocks (e.g., amino acids) needed to construct life. In 1950, a University of Chicago doctoral graduate student named Stanley Miller did an experiment to see if this could be made to happen in the laboratory. Using two glass jars (laboratory beakers) connected to each other by narrow glass necks (**Figure 4-2**), Miller filled one beaker halfway to the top with salty water to simulate the earth's early oceans and then pumped a mixture of air into a second beaker that simulated what he believed was the makeup of the early atmosphere (i.e., containing large amounts of ammonia and methane gases). Miller then lit a Bunsen burner below the ocean beaker to evaporate the water. The steam from this heated beaker then passed through a narrow glass neck to the second atmosphere beaker. Miller had electrodes placed in this second beaker which continually sparked to simulate lightening. The water vapor, after being stimulated by the electrodes, then passed through yet another glass neck to a condenser where the water vapor was cooled and changed back to liquid. The water was then returned via another glass neck back to the original ocean beaker. This cycle (ocean beaker to steam --> to electrically stimulated steam --> to condensed water --> back to ocean beaker) was repeated continuously over and over again. After just a few days, Miller started to notice a brownish scum-like coating building up on the inner surface of the ocean water beaker. He scraped off some of this scum and chemically analyzed it. The scum was found to contain small amounts of a few complex organic molecules that make up some biologic building blocks, including several different

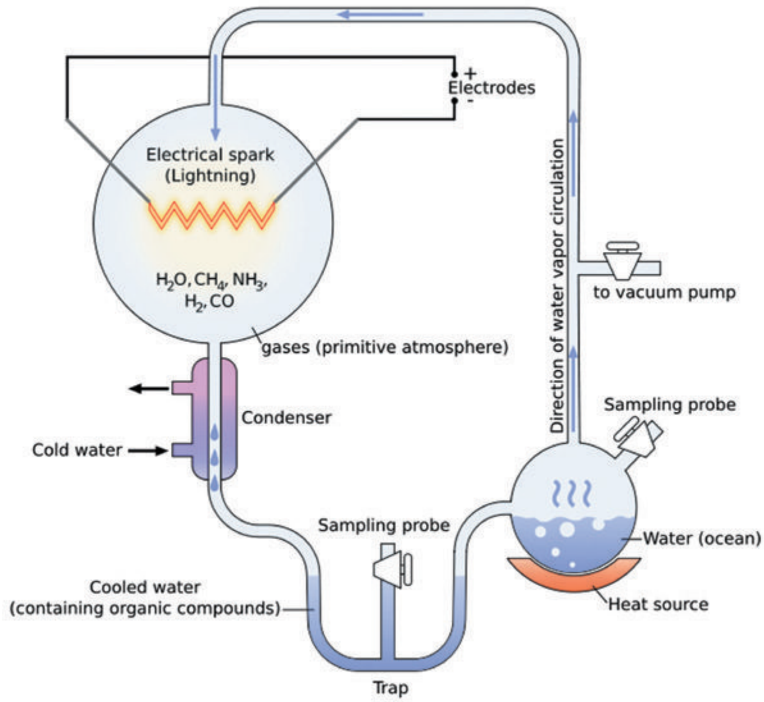

Figure 4-2 - A schematic diagram of the experimental apparatus that Stanley Miller used to demonstrate that an early atmosphere that contained large quantities of life friendly carbon, hydrogen, oxygen, and nitrogen atoms (e.g., methane, ammonia) might have allowed the development of carbon-based life on our planet. (Image credit: Wikipedia Commons)

varieties of biologically important amino acids, sugars, lipids (fats), and some building blocks for nucleic acids. Miller's landmark experiment, therefore, suggests the possibility that at least some of life's original chemical building blocks might have been the result of lightening from thunderstorms energizing the recombination or rebuilding of simpler molecules like water, ammonia, and methane (that contain the big four life critical elements, i.e., hydrogen. carbon, nitrogen, and oxygen) into some of the more complex biologic molecules needed to jumpstart life.

Unfortunately, Stanley Miller's "formula" for the composition of earth's early atmosphere is now thought to be incorrect. While scientists disagree as to what the specific chemical composition of the Hadean and early Archaen atmospheres might have been, many now believe it probably contained only small amounts of ammonia or methane. The early atmosphere more likely contained large amounts of carbon dioxide and water vapor, plus nitrogen and smaller amounts of hydrogen sulfide and sulfur dioxide and other volcanic gases. Other scientists point out that the extreme turmoil (intense bombardments including the traumatic birth of our moon) that the earth experienced during the 500 million year Hadean Eon might have caused numerous major changes in the chemistry of our atmosphere. Several scientists have subsequently repeated Miller's basic experiment using different mixtures of gases believed to be more representative of the earth's actual early atmosphere (i.e., with less ammonia and methane gas, but with other gases added that might have been present). Some of these more recent studies even used ultraviolet light to simulate actual sunshine rather than electrical discharges, which simulated lightening. Some of these studies have been able to replicate Miller's original results to some degree, in creating some amino acids, sugars and lipids, plus a few of the chemical ingredients needed to build nucleic acids. However, by reducing the amount of ammonia and methane gases in the simulated atmospheres, these subsequent studies all found significantly smaller quantities of these critical pre-biotic molecules. Thus, it seems that the earth's early atmosphere, while able to produce some of the basic building blocks of life, would have needed assistance from other sources to achieve the total volume of materials probably needed to jumpstart life. Where else could these critical building blocks for life be created? The key to answering this question seems to lie with the observation that the chemical makeup of life is much closer to the chemistry of star dust than it is to that of our rocky planet.

In chapter 2, we described how stars and planetary systems are created from the gravitational collapse of huge clouds of gas and dust that are located in interstellar space. These clouds are primarily made up of huge regions of leftover hydrogen and helium gas that was created following the Big Bang, but which have not yet been transformed into stars. While very rarefied (i.e., containing exceedingly small amounts of matter per unit volume), these clouds, which come in varying shapes, can be as wide across as tens to hundreds of light years with masses of thousands to millions of sun-like stars. They are, at least in our Milky Way galaxy, composed of approximately 97 percent hydrogen and helium gas plus about 2 to 3 percent dust. As noted in chapter 2, this dust consists of the heavier atomic elements, such as carbon, oxygen, silicon,

iron, etc., that were created by earlier generations of giant stars and expelled into interstellar space when these stars went into their supernova death throes. To expand on an earlier profound statement by Carl Sagan, *this dust is the "stuff" of both life and our planetary home*.

Our Milky Way galaxy contains a large number of these interstellar clouds (ISCs). **Figure 4-3** shows examples of two such clouds photographed by space telescopes. The clouds differ considerably in size, density, and even slightly in chemical composition. Many ISCs are currently in the process of giving birth to new generations of stars, while others seem to perhaps be beyond or nearing the end of "their child bearing years". Some ISCs have more main sequence stars embedded in them then others, which means that different regions of such clouds may be hotter or colder depending on how far they are from nearby stars. Different ISCs also have regions that are more dense (i.e., contain larger concentrations of gas and dust) than other regions. This extreme variation in terms of distances from neighboring stars plus the degree of densities of different cloud regions means that individual dust and gas particles may be exposed to quite different environmental conditions. Some particles may be closer to stars and receive more heat and radiation, while others may be far enough away to enjoy cooler or even cold conditions. Still other particles may be protected from the radiation of nearby stars by "hiding behind" or being imbedded in more dense clouds. This complexity of the environments in which the gas and dust particles of ISCs exist is now known to provide a variety of very supportive conditions that allow an even wider variety of very interesting types of chemistry to occur. It may be that much of the stuff of life may actually be manufactured in ISCs.

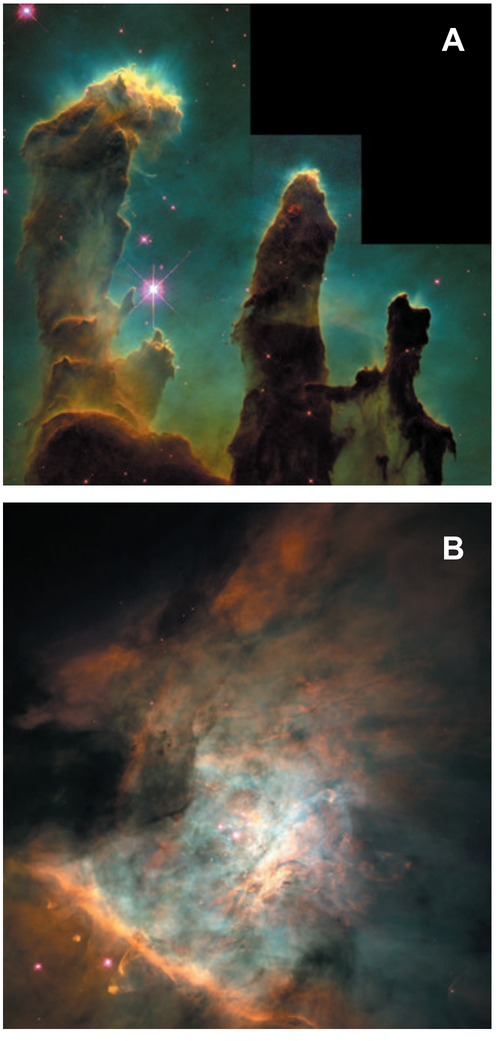

Figure 4-3 - Many galaxies, including our own Milky Way galaxy, contain numerous large gas and dust clouds where stars are born and die and where the environmental conditions are just right for the spontaneous creation of the complex pre-biotic organic molecules that are needed to allow the emergence of life. Shown are Hubble Space Telescope photographs of **A** what astronomers call the Eagle Nebula which is located in the Serpens constellation about 6,500 light years from earth (Image credit: NASA/ESA/J. Hester & P. Scowen, Arizona State University), while **B** shows the Orion Nebula. This very active "star nursery" is only 1,350 light years away and is the only nebula that is bright enough to be seen by the naked eye. It can be seen a little south of the Hunter's belt in the constellation Orion. (Image Credit: NASA/C.R. O'Dell & KWong, Rice University).

While astronomers long knew about the existence of ISCs and their role as "nurseries" in the creation of new stars, it was not until the end of the 20th century that we had the tools needed to probe what goes on within these clouds at the level of atomic physics or chemistry. At the end of the 20th century, the combination of space telescopes equipped with more powerful optical technologies plus more sensitive spectrometers allowed astronomers to gather information as to what kinds of chemistry was happening inside these clouds. These new space telescopes allowed scientists to see more than just the visible light normally emitted by celestial objects. They could now "see" at many other wavelengths of the electromagnetic spectrum, including the longer infrared, microwave, and radio wave regions, plus the shorter ultraviolet, x-ray, and gamma ray parts of the light spectrum. Examination of the electromagnetic energy in the infrared as well as the radio wave regions of the light spectrum that different kinds of molecules inside ISCs are sending our way has turned out to be especially revealing. It now appears that the formation of complex organic molecules (i.e., those molecules containing the critical atomic elements needed for life) may be a very common event inside ISCs. Hundreds of such organic compounds have now been identified including various types of amino acids, and other forms of complex carbon-containing molecules (e.g., hydrocarbons) that are critical to life and with each passing year scientists are discovering increasing numbers and more complex varieties of these organic molecules. The author needs to emphasize, however, that these complex organic molecules are themselves not alive in any sense of the word nor are they the product of any kind of biologic activity per se. They are instead the natural product of non-biologic forms of chemistry that is occurring inside these interstellar clouds (ISCs). Scientists use the term *pre-biotic* to refer to these types of molecules (i.e. they precede or are the critical precursors for later developing *biotic* molecules). However, many of these complex organic molecules are absolutely critical to the formation of the basic building blocks of life (i.e., those smaller macromolecules composed of between 10 and 30 atoms that are chained together to construct the gigantic macromolecules such as DNA or protein that are life's workhorses) that are necessary for the construction of carbon-based life-forms on earth.

Thus, after being created in stars and expelled in supernova explosions, some of the carbon, oxygen, nitrogen, phosphorus, and sulfur atoms, plus other heavier elements, become mixed together with hydrogen atoms and molecules, including water, ammonia, methane, and other varieties of hydrocarbons to form complex collections of grain-like or sometimes fluffy dust particles, many of which are coated with icy materials (**Figure 4-4a**). These small but complicated structures then become the *interstellar factories* within which complex chemistry can occur. Various kinds of complex organic (pre-biotic) molecules are slowly formed inside these dust grains by a complicated series of different chemical reactions. The icy surface of these dust grains both protects the developing molecules from stellar ultraviolet radiation that would normally tear such molecules apart, plus also provides a surface on which atoms and molecules can congregate and chemically interact with each other to form new and different molecules. Some of the chemical reactions that lead to complex pre-biotic molecules only

occur in the colder deep interiors of ISCs, while others may require the assistance of "just right" (i.e., not too strong nor too weak) doses of heat from neighboring stars. This "vital" dust (as the Nobel prize winning life scientist Christian de Duve calls these organic molecules that are formed in ISCs) then finds its way into the interiors of accretion discs where it becomes incorporated into the fabric of growing meteors, asteroids, comets, and other assorted objects that begin raining down on the surfaces of growing planets. Analyses of the chemical makeup of meteorites that have landed on earth have provided evidence that they do contain many varieties of complex organic molecules, including amino acids. Dust collected from comets has also been found (**Figure 4-4b**) to contain several varieties of complex organic molecules needed to build life. Therefore, in addition to providing us water, the early bombardment likely also provided an extremely important means of delivering life's critical building blocks directly to our planet's oceans.

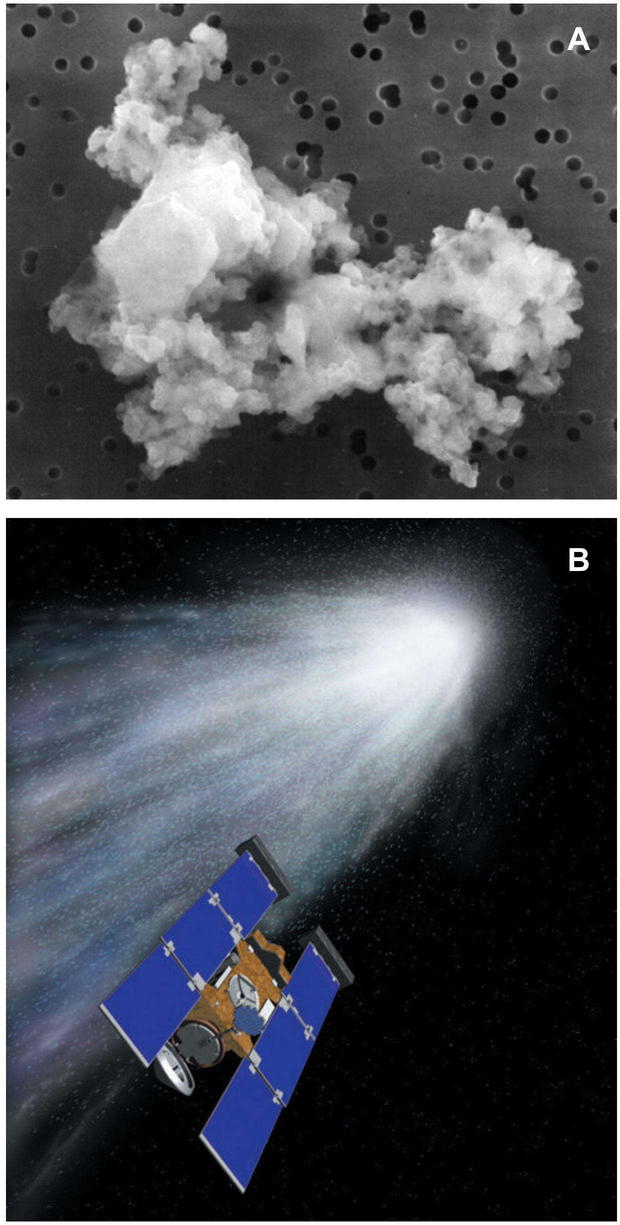

Figure 4-4 - **A** shows a microphotograph of a dust particle that was retrieved **B** by a recent unmanned NASA space mission that gathered and returned dust particles from the tail of a comet. The dust inside the tails of comets (as well as meteors) have been found to contain different kinds of complex pre-biotic molecules that originally formed in interstellar gas and dust clouds millions or billions of years earlier. (Image credits: NASA/JPL)

Therefore, it appears that, in addition to zapping the earth's atmosphere with lightening or strong sunlight, a second and probably more prolific source for the complex organic molecules that comprise the building blocks of life may be the complex chemistries that occur inside interstellar gas and dust clouds. Some scientists have recently attempted to experimentally confirm this possibility by simulating the ISC environment in the laboratory. Scientists (e.g., L. Allamandola, M. Bernstein, J.P. Dworkin, D.W. Dreamer, L.J. Sandford) at the NASA Ames Research Center

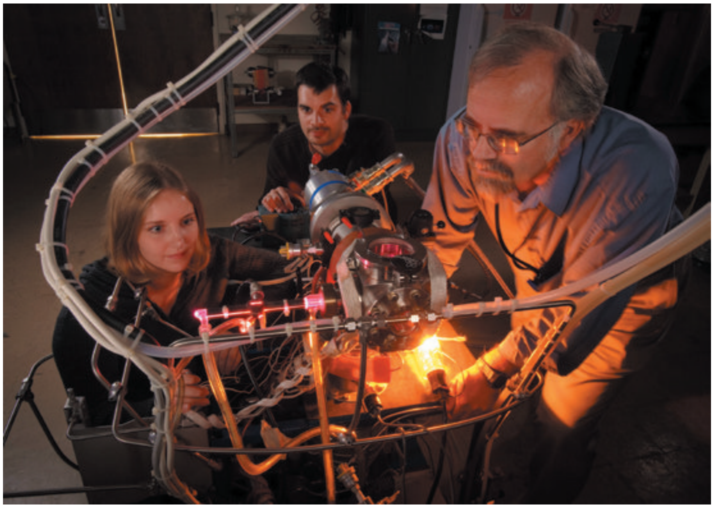

Figure 4-5 - Photograph taken at the Astrochemistry Laboratory of the NASA Ames Research Center in California which shows a special vacuum chamber that simulates the environmental conditions that occur inside interstellar gas/dust clouds. Experiments conducted at Ames and other laboratories have been successful in replicating the creation of complex pre-biotic molecules similar to those identified in interstellar gas clouds. (Photo credit: Dominic Hart/NASA)

in California, the SETI (Search for Extraterrestrial Intelligence) Institute, and the University of California, Santa Cruz have constructed special vacuum chambers and are attempting to artificially duplicate ISCs and find out what goes on within them (**Figure 4-5**). Since the density of the matter within even the densest ISC is far less than that of our atmosphere at altitudes of several miles above the ground, a vacuum chamber is needed. These small vacuum chambers have been filled with a collection (very small amounts, of course) of different gases (in the case of the SETI Institute studies, water plus sparse amounts of ammonia, methanol, and hydrocyanic acid) and dust that closely replicates the chemical composition of a typical ISC. Attached to the outside of the vacuum chamber, the scientists have positioned special "guns" that simulate heat and other forms of electromagnetic radiation coming from close-by stars. With these devices, it is possible to bathe the matter inside the chamber with specific types and doses of simulated stellar radiation. Now, instead of using space telescopes to search for funny infrared or radio wave chemical signatures emitted by tiny molecules located hundreds or thousands of light years away, these scientists are looking for funny looking smudges or discolorations inside the vacuum chambers and extracting samples for detailed chemical analyses. Using this technique, the scientists have now confirmed that many of the complex organic molecules that are crucial for assembling the different building blocks needed for life can be artificially created by this bizarre modern version of the classic "Frankenstein" experiment.

Finally, in addition to chemical reactions in the atmosphere plus special "air mail" deliveries by meteors, asteroids, and comets carrying cargoes of "ISC chemical factory products", a third source of the critical chemical ingredients or organic building blocks needed to jumpstart life on the early earth may have been those deep-sea hydrothermal vents at the bottom of the oceans (or subsurface hot springs like those found in Yellowstone National Park) that the heat loving varieties of the extremophiles call home. The deep-sea vents are associated with undersea volcanoes (and tectonic plate activity, to be described shortly) that is constantly spewing out water that is heated to high temperatures by magma rising from the hot interior of the earth. The hot water from these hydrothermal vents, which contains large quantities of dissolved high energy inorganic compounds (e.g. hydrogen gas, ammonia, nitrites, and sulfides) is chemically quite different from the colder surrounding sea water.

The mixing of the two kinds of water creates all sorts of chemical instabilities that could provide both the raw chemical ingredients as well as the energy source needed to synthesize some of the critical biological building blocks of life.

Thus, it seems by the time the horrendous bombardment period had finished pulverizing, melting, and possibly repeatedly destroying all early attempts to jumpstart life on our planet, the earth already had available three different but important sources for the critical chemical building blocks needed to get life started (**Figure 4-6**). The first, and probably the most prolific source being deliveries of "vital" dust from deep space, with lesser contributions from two additional sources including lightening or sunlight induced chemical reactions in the atmosphere, plus chemical reactions between hot water and certain minerals located near hydrothermal vents deep in the oceans, or at subsurface hot springs (e.g. Yellowstone National Park). All that was needed now was for things to calm down and cool down sufficiently to allow life to get beyond its very early and most vulnerable stages. In the remainder of this chapter, the author will outline the fascinating story of how life and planet earth co-evolved to produce a planet that is now teeming with life. This description will focus on only the high points of this story as a virtual mountain of excellent literature (plus videos, educational TV shows, etc.) is available if the reader wishes to become a guru at identifying and pronouncing the names of the millions of different life-forms that have come and gone throughout the ages. The purpose of this chapter is to attempt to outline and describe the process by which one (possibly) typical form of carbon-based life arose on one typical type of planet in one small corner of the universe.

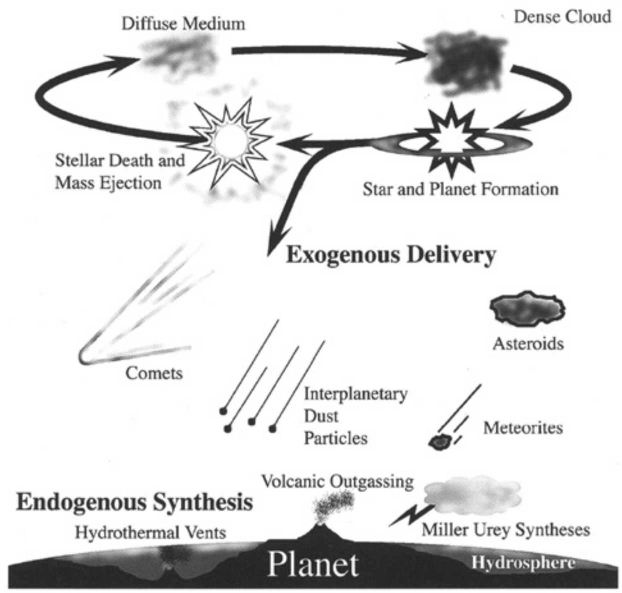

Figure 4-6 - An artist's drawing which depicts the three major means by which complex pre-biotic molecules may have been created and made available on the early earth for life building projects. (Image credit: NASA Ames Research Center/NASA)

Archean Eon Allowed Life to Quickly Gain Permanent Foothold on Earth

The period from 4.0 bya to approximately 2.5 bya is labeled by geologists and earth scientists as the Archean Eon (which loosely translates as "time of ancient life"). While this new chapter in the earth's history started as a somewhat subdued version of its Hadean Eon "hell on

Figure 4-7 - Shows an artist's drawing of what the earth may have looked like early in the Archean Eon, about 3.5 billion years ago. At that time, the earth was covered mostly with oceans (land masses were just beginning to slowly develop). While the sun was cooler than today, the larger amounts of carbon dioxide gas in the atmosphere created a greenhouse effect which made both the atmosphere and oceans hotter than they are today. Because of the extreme heat and lack of oxygen, the only life-forms that could survive were the heat loving extremophiles similar to those found today around hot hydrothermal vents in the deeper parts of the oceans as well as primitive cyanobacteria which lived in mound-like stromatolite structures located in the shallow waters next to the newly growing proto-continents. (Image provided courtesy of Smithsonian Institute. Painting by Peter Sawyer)

earth" predecessor, during the next 1.5 billion years the prevailing climatic and geological conditions gradually became more and more life friendly. **Figure 4-7** shows an artist's drawing of how the Earth's surface may have appeared during the early part of the Archean Eon.

Before life could arise and survive on Earth, the planet had to undergo a dramatic "cool down" in order for it to develop a reasonably long term and stable climate that was temperate enough to support the slow-paced development of carbon based life-forms. In addition to the distance from its home star, the major factor that drives the environmental climatic conditions of any planet is the amount of heat that is contained in the interior (subsurface) regions and the manner in which this heat is dissipated (removed) to outer space over time. Four different types of heat are produced in the interiors of all planets during the formation period and subsequently following the end of the formation period. During the accretion phase of planet formation, the continual collisions between the large planetesimals and the developing earth produced an incredible amount of the first and most intense form of heat known as ***impact-related heat***. This type of heat was so intense that most of the forming planet remained in a super-hot molten state until the end of this phase. Initially, the materials inside the molten earth were thoroughly mixed together in a homogenous fashion but they soon began to separate as a result of differences in the mass (weight) of different materials. This *differentiation phase*[3] resulted in the heavier iron and nickel settling toward the center of the earth to form the core while the lighter materials (e.g., silicates and other rocky materials)

[3]You get the same "differentiation" effect if you add small rocks (gravel or sand), oil, and water into a jar and shake it up. At first, the contents are all mixed together in a homogenous fashion. However, if you place the jar on a table you will soon see the rocks sink to the bottom and the lighter oil rise to float on top of the water.

rose to the surface to form the upper mantle and the surface crust. The rubbing of the lighter and denser materials against each other as they moved upward or downward inside the earth produced the second type of internal heat, known as ***frictional heat***. It was not until the later part of the bombardment period of the Hadean Eon that the impact and frictional heat had sufficiently dissipated to space to allow the earth to form a solid outer crust.

While the impact and frictional forms of internal heat had mostly dissipated by the early part of the Archean Eon, a third source of internal heat remained, which is still with us today. This source is related to the earth's ***hot molten core*** which is where, during the differentiation phase described above, the heavy nickel and iron settled. While the early earth was much hotter and had a larger molten interior, the earth today still retains a relatively large molten core which, while cooler than it was in earlier years, is still quite hot (the current core temperature is approximately 6,093 degrees Celsius, or 11,000 degrees Fahrenheit, which is hotter that the approximate 9,000 degrees F temperature of the sun's surface).

Finally, the fourth source of internal heat that occurs in all rocky planets and which still exists today in the interior of the earth is one associated with the ***radioactive decay*** of unstable atomic elements. This is a process in which certain unstable forms of atoms spontaneously transform into a stable form of a different type of atom. As mentioned in an earlier chapter, the number of protons in the nucleus of an atom is usually equal to the number of neutrons. Whenever an atom contains a different number of neutrons than protons, we call it an ***isotope*** of that specific element. While most naturally occurring isotopes of the Earth's 92+ types of atomic elements are stable, some of these isotopes are unstable in the sense that they tend to spontaneously decay (the technical term is *transmute*) into a stable form of a different element. Examples of some heavy elements that have unstable isotopes include uranium (U), thorium (Th), and potassium (K). Uranium and thorium both decay to stable isotopes of lead while potassium decays to argon (Ar). The element carbon (which typically has 6 protons and 6 neutrons in its nucleus) even has one isotope that is unstable, and that is carbon-14 (i.e., carbon that contains two extra neutrons). When it decays, it changes to a stable form of nitrogen which has 7 protons and 7 neutrons in the nucleus. (Carbon-14 is extremely valuable for helping paleontologists determine the ages of some of the fossils they find in rocks.) When unstable atoms undergo *radioactive decay*, they emit sub-atomic particles from their nuclei (which may, depending on the specific isotope, include protons, neutrons, or other high energy forms of radiation such as neutrinos, gamma rays, etc.) and in the process generate a small amount of heat. When several billion or more individual unstable isotopes undergo decay all at once, a substantial amount of heat can be generated. While unstable isotopes of different atomic elements are present everywhere, their relative numbers are small compared to the vast numbers of the more common stable varieties. The interior of all rocky planets contains a substantial amount of these various unstable isotopes whose collective radioactive decay over time results in a continual creation of an additional heat source. Therefore, in contrast to the impact- and friction-related heat sources that had mostly dissipated by the early part of the Archean Eon, the heat associated

with the molten core of the earth and radioactive decay of unstable elements, while steadily decreasing over the past 4 billion years, are still present today.[4] These two remaining heat sources will continue having a significant influence on the earth's geology and climate for at least another three or four billion years.

Figure 4-8 - Photograph of the most recent 1980 eruption of the Mt. St. Helens volcano in Washington State. (Image credit: United States Geological Service, i.e., USGS)

Perhaps the most dramatic (i.e., TV and newspaper headline making) means by which heat is removed from the interior of the earth is through the action of volcanoes (**Figure 4-8**). Volcanic activity involves a more active form of heat transfer that allows super-heated materials (gases and molten rock) to physically move from hotter subsurface regions to the surface of the earth. The reader is no doubt familiar with television or movie images of volcanic eruptions that spew huge clouds of gas, smoke, and hot debris high into the atmosphere, and produce flowing rivers of red hot lava (melted rocks and other subsurface materials). Volcanoes develop from large super-heated molten pockets of materials located deep in the earth that, over time, literally "melt their way" to the surface of the earth to form a tunnel or underground channel that then provides a highway for the periodic movement of hot gases and molten lava to the surface. These pockets of hot molten materials frequently develop in two different ways. The first occurs on the ocean floors far from the traditional continental landmasses. Narrow plumes of hot rock rise from deep in the mantle to the surface to produce what is called *hot-spot* volcanism. The volcanoes in the Hawaiian Islands and the extremely large and dangerous one located beneath Yellowstone National Park in the United States are examples of this type of volcanic activity. The second type of volcano typically occurs on the coastal regions of continents directly above subduction zones (associated with a geological phenomenon called *plate tectonics* that we will discuss shortly) where a slightly heavier continental (tectonic) plate has encountered an adjacent lighter plate and is diving underneath the first plate. The heat produced by the subduction process results in a *melting zone* in which molten lava is pushed up to the surface to form volcanoes as well as assist in building mountains and continents. Since the major source of gases in the early atmosphere were those that were being outgassed from

[4]Some earth scientists have recently begun to believe that the degree of heat from the radioactive decay of unstable atoms may have been sufficiently more intense during the accretion phase of earth's development that it might have actually played a greater role than the impact- and friction-related heat sources in keeping the entire planet in a constant molten state during this time.

the earth's interior by volcanic activity, the average atmospheric temperature itself was probably hotter than it is today, perhaps rivaling the hottest deserts on today's earth with temperatures as high as 120 degrees Fahrenheit (49° Celsius) or higher. In addition, the volcanoes also provided an assortment of what today would be considered noxious or poisonous gases including carbon monoxide, sulfur dioxide, plus hydrogen sulfide and hydrogen chloride. No free oxygen was yet present in the atmosphere.

Therefore, at the time that many scientists now believe the first life-forms emerged in the early part of the Archean Eon, the earth was not yet very life-friendly, at least by mankind's current standards, but as we will soon see, it was well on its way to becoming such a place. At the beginning of the Archean Eon, the earth was virtually a "water world" (90 percent of the surface was covered by oceans) but one quite different from that depicted in the movie with the same name starring Kevin Costner. The first true continents would not start developing for almost another half billion years, and the only structures sticking above the surface of the oceans were an occasional rim of an impact crater, or possibly small outcroppings (similar to the Hawaiian volcanic island chain) of some of the active volcanoes that were sprinkled all over the bottom of the oceans. As a direct result of the intense volcanic activity, the ocean floors were littered with large numbers of active volcanoes which made the oceans hotter than today's oceans, even at some of the deeper depths, which today may be quite cold. The continual outgassing from the volcanoes also put a mixed bag of gases plus hot dissolved minerals of various sorts into the water. As we will see next, this latter effect may have been a "good thing" with regards to the origin of life.

If the first life-forms were indeed present by as early as 3.5 to 3.8 bya, where did they live and how did they make their living? One thing is sure - the first life-forms would have had to "like it hot". In 1977, scientists made a dramatic discovery of strange microbial life-forms that today live deep in the oceans near hot hydrothermal vents. Hydrothermal vents are associated with undersea volcanic and plate tectonic activity on the seafloor that allow hot gases and molten materials (lava) to surge up from deep in the earth into the ocean waters. This is where one form of the so-called e**xtremophiles** has taken up residence. In 1977, scientists from the Woods Hole Oceanographic Institute boarded a special ocean-going submersible vehicle named "Alvin"(which is about the size of a Volkswagen Beetle automobile) that had been specifically designed to dive to depths of 2 miles or more to the ocean floor where the extreme weight of the overlying water would instantly crush a normal submarine (**Figure 4-9a**). The scientists were diving to a hydrothermal vent system located close to the Galapagos Islands off the coast of South America (Charles Darwin's old stomping grounds). The scientists were using strong search lights attached to the front of Alvin to illuminate any strange objects they might find near the vents. And, strange objects they indeed did find! Instead of a relatively flat ocean bottom littered with a few scattered rocks and other debris, plus occasional small sea creatures (fish, and other small deep sea animals) swimming around, they encountered a region containing a large

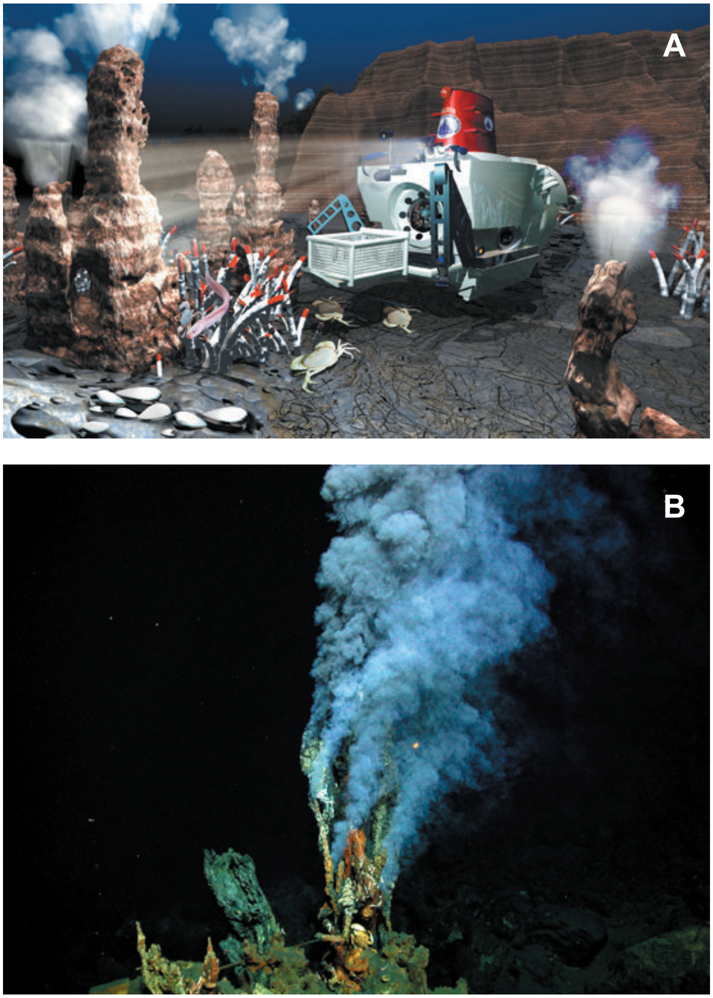

Figure 4-9 - A. Artist's view of the Alvin deep sea diving submarine used for manned exploration of hydrothermal vent systems. Normally, at this extreme depth everything would be in total darkness except for what could be seen with Alvin's spot light. The artist has taken the liberty of drawing everything as it would appear if a giant (football stadium) type lighting system was present. (Image credit: David Barczak, University of Delaware, Copyright 2009). **B** shows a high resolution photograph of the Mariner hydrothermal vent system with black smokers and hot steam rising from below the ocean crust (Image provided courtesy of C. Fisher of the Pennsylvania State University and the National Science Foundation Ridge 2000 Program).

number of tall "cigar shaped" black rock-like structures sticking up vertically from the bottom of the ocean floor. These strange objects vaguely resembled the smoke stacks often seen on factories or homes (**Figure 4-9b**). These objects, which scientists later labeled black smokers were large (with some having heights of 8 feet or more) and were constantly spewing a very hot and dark smoke-like material straight up out of openings located at the top of the structures. Swimming all around in the vicinity of the black smokers, the scientists observed a very large assortment of various types of sea life. Some of these critters resembled shrimp and crabs while others resembled small fish and mussels. There was even some extremely long (6 foot or more) skinny "worm-like" organisms (later dubbed by scientists as *tube worms*) that were totally unlike any creatures that the scientists had ever seen before (**Figure 4-10**).

These unusual hydrothermal vents surrounded by large populations of strange sea life have subsequently been found in oceans all over the world. They are typically located close to the spreading centers of tectonic plates at depths of 1.5 miles or greater below the ocean surfaces. While ocean water at extreme depths is normally quite cold, the waters around the black smokers of these hydrothermal vents are extremely hot due to geothermal heat

coming from the interior of the earth. It now appears that complex biological ***ecosystems***[5] exist around these different hydrothermal vent systems. At the base (i.e., the bottom "rung or step" of the complex food chain "ladder") of these ecosystems are the single-celled heat-loving thermophiles. While the thermophiles themselves may not be dependent on sunlight as an energy source (they thrive on chemical instabilities triggered by geothermal heat), many of the larger (macroscopic) life-forms that depend on their thermophile neighbors as their main sources of daily meals do need the oxygen that is dissolved in the seawater.

Figure 4-10 - Photograph of the tube worms that scientists found living near the hydrothermal vents. Some of these creatures may be as much as eight feet long. They have no digestive tract, but their hollow interior is filled with heat loving extremophile bacteria. The tube worm provides the bacteria with nutrients that they need to live and the bacteria, in turn, convert oxygen, hydrogen sulfide, and carbon dioxide into nutrients that the tube worms need to live. (Image credit: National Oceanic and Atmospheric Administration Ocean Explorer Program/Monika Bright, University of Vienna, Austria)

Carl Woese and his students, in performing their genetic mapping studies, have found evidence that the thermophiles among the extremophiles are genetically the closest species to the base of the tree of life or the first common ancestor of all current life-forms. The question of exactly where (and when) the first single-cell life-forms managed to establish a permanent foothold on earth may never be known for sure. It is quite possible that life may have undergone many false starts followed by extinctions during the Hadaen and early Archean Eons. At the peak of the heavy bombardment period many of the impact collisions would have been severe enough to completely evaporate the oceans and sterilize the earth, i.e., destroy any life that had managed to get started. The fact that thermophiles living in the bottom of deep oceans near hydrothermal vents would have had a greater distance plus a greater water shield between themselves and the surface impact zones might have given them an advantage in possibly surviving all but the most devastating collisions. Thus, while it is possible that the themophiles

[5]An *ecosystem* is the term life scientists use to describe a complex "food chain" made up of a large number of different animal and plant species that live together in one environmental region and which are dependent on each other for their primary food source. For example, the ocean food chain begins with large numbers of tiny or microscopic plants and animals collectively called *plankton* that live close to the surface of the oceans. The plankton are the primary food source for smaller fish and other forms of sea life that live just below them in the ocean. These fish are, in turn, the primary dinner choices for larger marine animals. If the plankton disappeared, the fish would starve and disappear and the large ocean sea life would also perish. On land, similar ecosystems are formed by different species of plants and animals. The survival of whole species becomes threatened whenever their primary food source in the local food chain is taken away for whatever reason.

were themselves the Adams and Eves of all life on earth, it is also possible that they may not be. They may instead be the descendents of earlier now extinct life-forms that remained behind in regions closer to the surface of the oceans rather than evolving into and filling empty environmental niches in safer regions at the bottom of the ocean. With the cessation of the heavy bombardment era, these bottom dwelling heat lovers may have been the only surviving species and by default became the ancestor of all future life, including man.

Once the bombardments settled down to the point that sterilizing (life-ending) impact events became history, the single-celled thermophiles were able to begin relocating (evolving) from their deep-sea "safe zones" into near surface regions of the oceans as well as the shallow offshore regions adjacent to the newly developing proto-continents. On or about 3.5 bya, a major evolutionary development occurred. The first oxygen producing bacteria apparently appeared on earth. These bacteria had somehow managed to master at least the first early form of a complex biochemical process called ***photosynthesis***. Photosynthesis is the process by which all modern plants are able to take energy from sunlight, mix it together with carbon dioxide (CO_2) and water and make sugar (glucose) which they then use as a food source to construct ATP energy molecules. During the photosynthesis process, free oxygen is created and expelled into the atmosphere as a waste product. As we will shortly see in the present book, the production and release of free oxygen into the atmosphere was both the greatest "curse" as well as the greatest "blessing" that could have happened to life on earth.

The Archean Eon, which extended from 4.0 to 2.5 bya, therefore witnessed the beginning of the first primitive life-forms on earth. As mentioned at the beginning of chapter 3, the earliest tentative evidence (i.e., presence of lighter isotopes of carbon which appear to be of biologic origin) was found in rocks that formed approximately 3.8 bya. More definitive evidence of what appears to be the fossilized remains of single-cell organisms (see Figure 3-1) has been uncovered from rocks found in both South Africa and Western Australia. This newer evidence, which has been dated to approximately 3.5 bya, was found in unusual forms of layered rocky-like structures labeled by paleontologists as ***stromatolites***. (see Figure 4-8 for an artist's drawing of an early Archaen landscape scene that depicts such stomatolite mound-like structures in shallow offshore waters.) These layered rock-like formations are virtually identical to similar structures, known as ***bacterial mats*** (which some scientists have labeled "modern stromatolites" because of this remarkable similarity) that are found today in a few shallow water coastal areas that are known to be formed by living colonies of single-celled bacteria (**Figure 4-11**). These modern mats are inhabited by modern cyanobacteria that rely on the chemical process of photosynthesis to build their own food, while a few bacteria in the next lower layers of the mats use organic molecules that are expelled as waste products by the photosynthetic bacteria living above them. Hiding in the most bottom layers of some of the modern stromatolite structures are more primitive single-cell forms that do not use oxygen and for whom oxygen is in fact lethal. Only a very small handful of these modern stromatolite communities exist today since, in contrast to those of the Archean time period, they are typically eaten by modern-day scavengers.

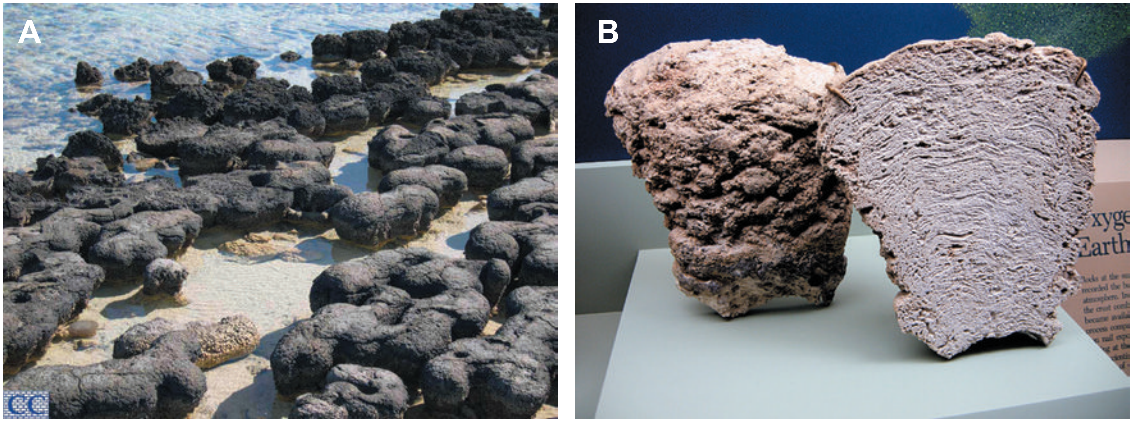

Figure 4-11 - Although oxygen was fatal for most life-forms during the early Archean Eon, one variety of bacteria evolved about 3.5 bya that used an early form of photosynthesis to provide its energy needs which involved the elimination of oxygen as a waste product. These single-celled prokaryotes lived together in large colonies that numbered in the millions. They continually excreted waste materials that turned into solid materials that, over long periods of time, came to (**A**) resemble rocky-like mounds that paleontologist's call stromatolites (Image credit: Cambridge Carbonates Ltd). When cut into thin cross sections (**B**) these structures exhibit a layered appearance. (Image provided courtesy of Douglas J. Eernisse)

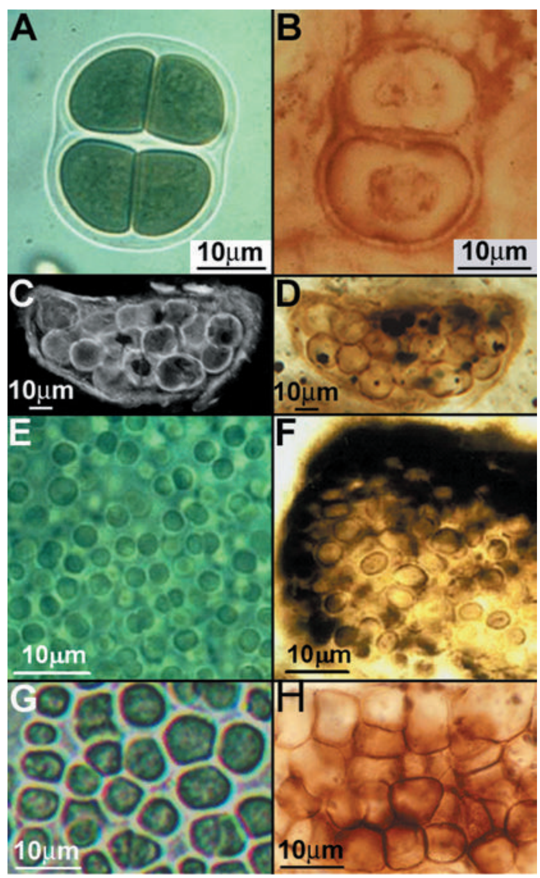

Figure 4-12 - Microphotographs of a variety of different modern-day oxygen producing cyanobacteria (left side of figure) along with a series of photomicrographs (right side) of "equivalent" fossilized microbes that lived in ancient stromatolites during the Proterozoic Eon. The ages of the fossilized microbes shown on the right are estimated to range from .65 to 2.1 billion years. (Images provided courtesy of Dr. J. William Schopf)

The fossilized single-cell microbes found in the African and Australian stromatolites appear to be very similar in size and shape to modern ***cyanobacteria,*** also known as blue-green algae (**Figure 4-12**). While the earliest stromatolite structures so far found date to approximately 3.5 bya, scientists believe that by the end of the Archean (2.5 bya) they were present worldwide in most shallow water coastal regions.

Although the first oxygen-producing bacteria had apparently taken up residency on the primitive earth by as early as 3.5 bya, the transition to an aerobic lifestyle for most life-forms on earth would be very slow in

developing. For the remainder of the Archean Eon and well into the next Eon, which earth scientists call the ***Proterozoic Eon***, the microscopic prokaryotes would remain the dominant life-forms on earth, and they would continue their anaerobic lifestyles in which oxygen would remain poisonous and something to be avoided at all costs. While the prokaryotes were slowly evolving and a few were getting more sophisticated (e.g., developing more complex and efficient photosynthetic mechanisms), in general nothing very exciting seemed to be happening in terms of the evolution of life, or at least it seems that way since we have very little fossil or other types of evidence to tell us otherwise. It would not be until around 1.7 bya that the next major step in the evolution of life would pop up in the fossil record. Sometime around a billion years after the start of the Proterozoic Eon, the much larger and biologically more complex eukaryote type of single-cell organisms first made their appearance in the earth's fossil record. Then, starting shortly before 1 bya, another major evolutionary advance occurred when the first multi-cellular life-forms arrived on the scene. While the period from approximately 4.0 to just before 1 bya was, in terms of the development of life, relatively "quiet", "slow", and definitely not worthy of any banner newspaper headlines, the earth itself was busy undergoing a number of dramatic geophysical changes that not only facilitated the emergence of life itself but was also fostering and encouraging its continued survival as well as future biological evolution. Earth and life were truly co-evolving! In the next section of this chapter, I will take a short break from the discussion of issues related directly to development of different life-forms, and describe some geological and geophysical phenomena that were very critical in determining "how" and "why" planet earth is as life-friendly as it is.

End of Archean and Beginning of Proterozoic Eon Witnessed important Geological Changes that Dramatically Increased the Pace of Life's Evolution

When someone asks the question of what it is about a piece of real estate property that makes it a truly great place to live, the answer given is typically "location, location, location". The same can be said for planet Earth. The orbit of Earth is just far enough away from the sun that it is possible to maintain oceans of liquid water. We live in what astronomers refer to as a *continuously habitable zone* (**Figure 4-13**). While carbon-based life of the kind we know on earth can exist in lots of strange or bizarre environments, the one thing that it absolutely cannot do without is liquid water. Steam or ice will not do, it must be liquid at least some of the time. However, it is not the distance itself of the earth from the sun that allows liquid water to exist. If the earth had no atmosphere, the average surface temperature today would be well below the freezing point of water (i.e. close to –18 degrees Celsius, or 0 degrees Fahrenheit). Today's sun itself does not produce enough heat to melt ice, and the sun 4.0 bya, because of its youth (all stars slowly increase their heat output over the course of their main sequence lives), was 30%

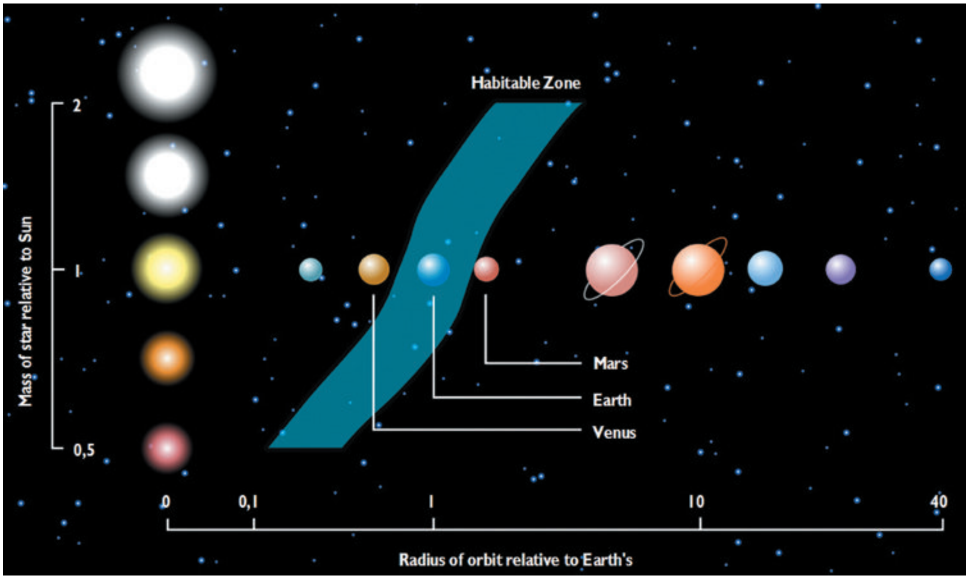

Figure 4-13 - Depicts the size of the continuously habitable zone that surrounds stars the same size, or slightly smaller or larger than our sun. Any planets which have orbits within this zone have the potential (depending on other geologic conditions, e.g., presence of an atmosphere) to be warm enough to allow liquid water to exist on their surfaces. (Image credit: Wikipedia Commons)

cooler than it is today. In the absence of an atmosphere, the average surface temperature at that time would have been even colder. So, why is it that the Archean Eon climate was possibly as much as 40 to 50 percent hotter than it is today and why is it that we are not frozen today? The answer is that our atmosphere contains certain specific types of gases that act to trap some of the sun's heat and prevent it from reflecting off the earth and escaping back into space. Scientists refer to this heat retention effect of the atmosphere as the *greenhouse effect* (**Figure 4-14**). It is the same effect that occurs in the winter when your car is sitting in the sun with its windows rolled up and what happens inside a gardener's greenhouse during cold weather. The car

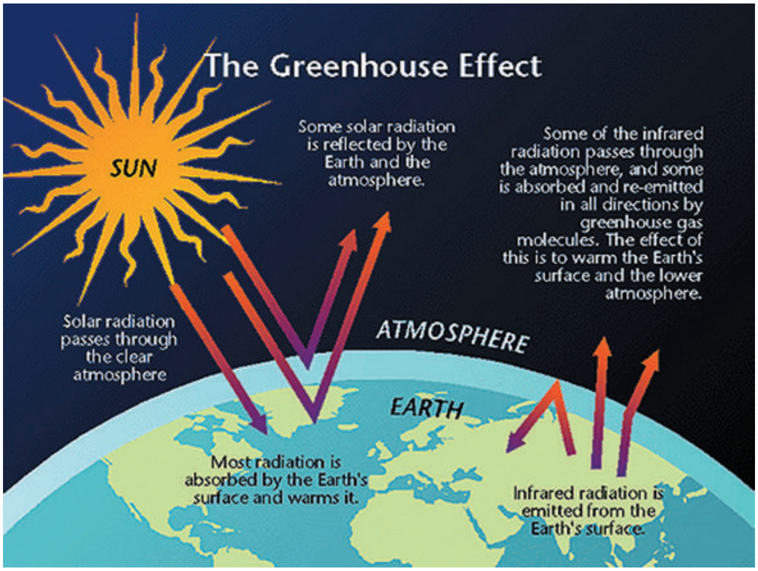

Figure 4-14 – Illustrates the nature of the earth's atmospheric greenhouse effect. (Image credit: NASA)

windows and greenhouse glass roof, while allowing sunlight to enter will impede the heat from escaping. The primary gas in the atmosphere that serves the same function as the glass windows and roof is carbon dioxide (CO_2). Water vapor and gases like methane and ammonia also can act as greenhouse gases. So, the primary reason the atmosphere during the Archean Eon was hotter than it is today, even though the sun was cooler, is that more CO_2 was present to trap the sun's heat. The early Archean atmosphere may have contained as much as 10 to 15 percent CO_2 as contrasted to only .04 percent today.

Therefore, greenhouse gases in the earth's atmosphere have continually acted over the past 4 billion years to assist in keeping our planet temperate enough to allow water to continually remain in a liquid state for extended periods of time. In addition to this heat trapping role of greenhouse gases, there has been a second and even more critical geological phenomenon that has continuously acted to maintain the temperature of the atmosphere at a relatively stable level. ***Believe it or not, the earth has its own feedback thermostat system for regulating atmospheric temperatures***. This thermostat system essentially involves a feedback mechanism by which the amounts of greenhouse gases (and, especially, carbon dioxide) which are present in the atmosphere at any moment in time is controlled by the current weather conditions and, in particular, the current temperature of the atmosphere. To put it simply, *if the air temperature gets hot, CO_2 is removed from the atmosphere which causes the greenhouse effect to decrease which cools things down and, if the climate gets cold, CO_2 builds back up in the atmosphere to cause the greenhouse effect to increase and warm up the planet*. While the preceding statement conveys the essence of how the earth's thermostat system works, it is an oversimplification that I will need to expand on in order to more accurately depict what actually happens.

In order to better understand how the earth's atmospheric temperature regulating system works, I will need to further describe how the earth deals with its own internal heat. As stated above, following the completion of the planetary accretion process and the tumultuous Hadean bombardment saga the two major internal heat sources that still needed to be dealt with were the radioactive decay of unstable atomic elements and the earth's hot molten core. The way in which the earth deals with these two remaining heat sources is via a physical phenomenon called ***convection***. Heat convection is the mechanism by which different materials (solids, liquids, or gases) in the earth's subsurface, when heated, tend to expand and become less dense and move toward cooler surface regions. This convection phenomenon can be easily seen when we heat liquid materials such as water. As a pot of water that is filled to the brim heats up, it comes to a "boil" in which the water expands, rises, and then spills over the side, and as it continues to heat further it becomes even less dense and transforms into rising steam. A similar thing happens to the so-called "solid" materials (e.g., rocks) deep in the earth when they are heated by the nearby molten iron/nickel core. They heat up and expand and when they expand they become less dense and tend to rise up toward the cooler regions of the upper mantle and crust. When the materials reach higher cooler regions they then cool down (in essence they pass their extra heat to the earth's surface, then to the atmosphere, and finally to space),

contract, become more dense, and begin moving downward again toward the hotter regions (where they "collect" another load of heat to then be brought back to the surface and released to space). Because of the continuing presence of a hot molten core and radioactive decay, the different materials in the entire mantle of the earth is in a state of convection-related movement that produces a mixing of different materials as well as recycling of specific materials into and out of the deeper subsurface of the planet. It is this extremely slow heat-related "churning" of the entire planet that has provided the earth with the long term existence of a relatively life-friendly climate as well as the creation and proliferation of our continental land masses.

However, before we can really understand how the earth deals with its internal heat to allow the existence of a temperate and life friendly surface environment, the author will need to present a few more geological facts. **Figure 4-15** shows a basic schematic drawing of the internal structure of the earth. While the inner core (made largely of solid nickel and iron) is extremely hot (11,000 F), things do get gradually cooler as we proceed toward the surface. The crust of the earth is, compared to the rest of the planet, extremely thin, being only about 25 to 30 miles in thickness. Although not even close to being as hot as the mantle and core regions, the lower parts of the crust are hot, being close to 1800 degrees Fahrenheit (982° C) at a depth close to 30 miles. In fact, in diamond mines in northern Canada, where the surface temperature might be well below freezing, miners cannot remain at depths much beyond a half mile for very long without risking heat exhaustion. Unfortunately, most published illustrations or drawings of the earth, including Figure 4-15, show the crust as being solid and continuous over the entire surface of the planet. This, however, is not the case. ***One of the truly startling geological discoveries of the last half of the 20th century was that the crust of the earth is not a single continuous structure that extends around the world but is separated into at least 12 distinct plates of different sizes that lie adjacent to each other.*** **Figure 4-16** depicts the geographical location of each of these unusual discontinuities or "cracks" in the earth's surface which separate the different crustal structures that geologists now call ***tectonic plates***. Earth, in fact, may be the only planet in our solar system to presently possess a crust made up of tectonic plates. The importance of such plates for facilitating life friendly environments will be discussed next.

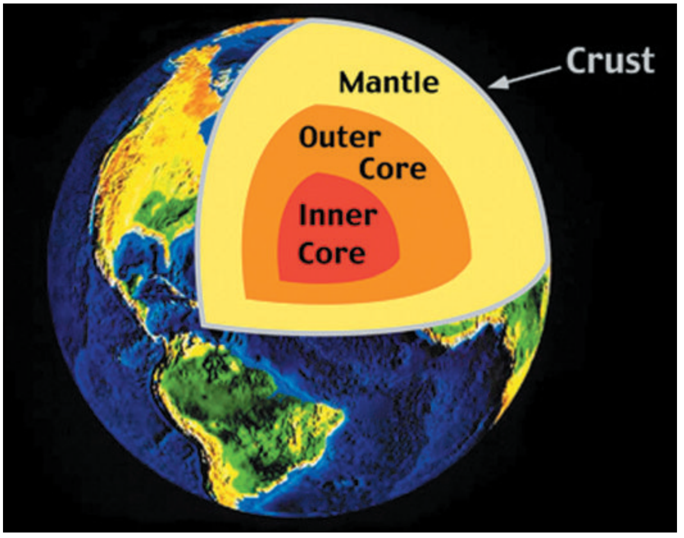

Figure 4-15 - Illustrates the internal makeup (structure) of planet Earth. (Image credit: Dr. Michael Pidwirny).

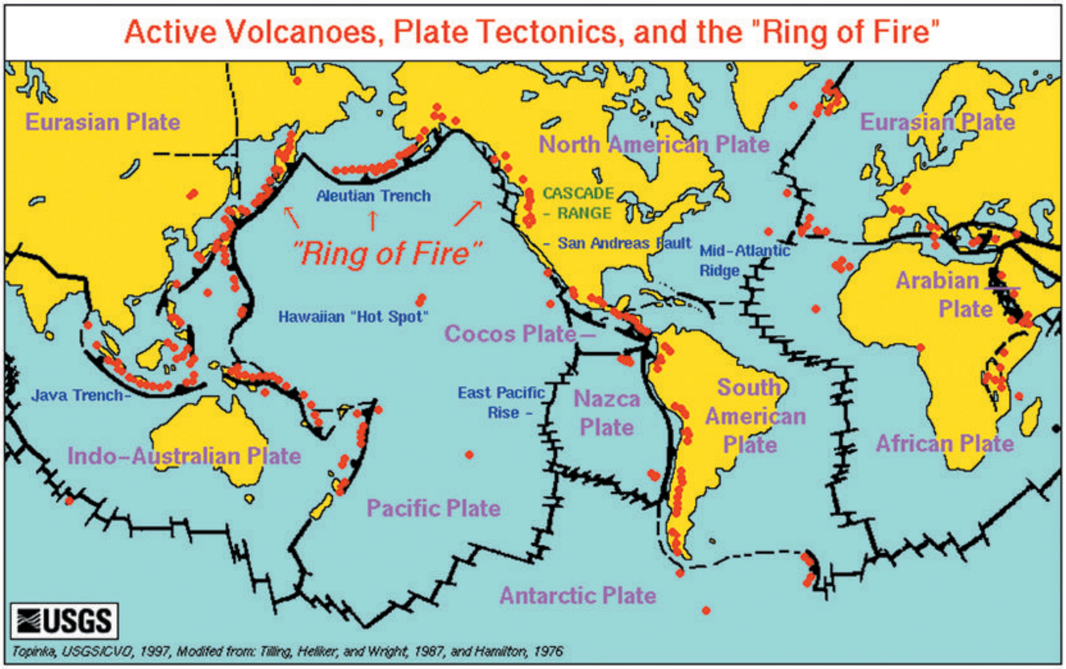

Figure 4-16 - Shows (black tracings) the location and extent of the individual tectonic plates on our planet. Also depicted is the infamous "Ring of Fire" (red dots) which is the location of active volcanoes that are located mainly along the boundaries where two adjacent tectonic plates are actively colliding with each other. Those where the northern part of the Pacific Plate is encountering the Eurasian Plate and the North American Plate are the most dangerous since they are located in more heavily populated regions of the world. (Image credit: USGS)

Figure 4-17 shows an artist's drawing of what happens as the convection currents continually transport materials back and forth between the hotter lower mantle and the cooler upper mantle regions of the earth. This continual rising and falling heat-related phenomenon can be depicted as a series of *circular convection cells* that lie directly below the surface crust. The boundaries between adjacent crustal or tectonic plates are referred to by geologists as ***spreading centers***. This boundary region consists of a very narrow area where the edges of the two tectonic plates are shoved up against each other. If a series of active convection cells are positioned below and along the length of the spreading center, they will continually push molten lava upward. The rising lava will cause the two plates to move apart and the new lava will fill in the empty space between the plates to create new ocean floor (crust). While some tectonic plates are covered almost exclusively by oceans, other plates have large continental land masses (which are made up mostly of lighter less dense granite rocks) sitting on top of them. Still other tectonic plates are covered by a complex mix of both oceans and continents. Over time, as new ocean crust is laid down at the spreading centers, the individual plates and any continental "passengers" they might have will move further apart. Of course, if two adjacent tectonic plates are moving toward

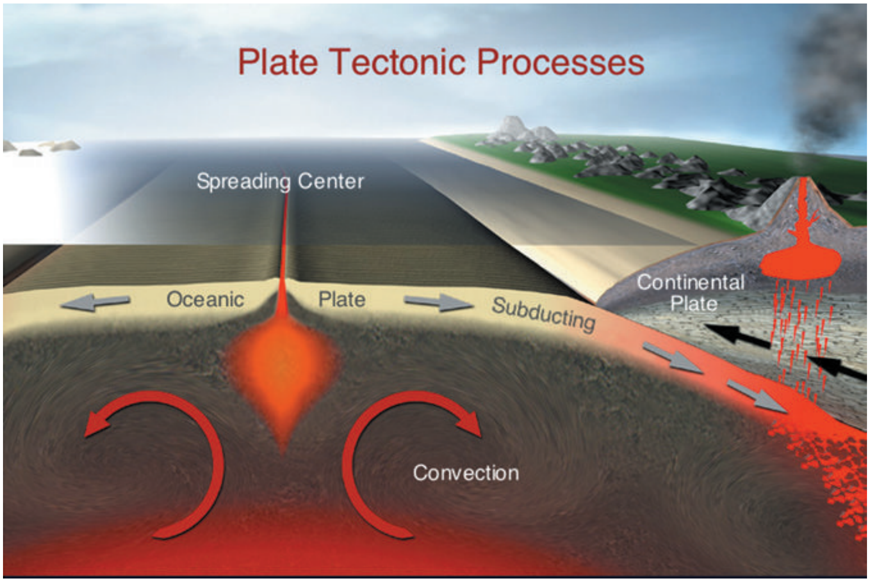

Figure 4-17 – Illustrates the process by which hot magma rising from beneath the crust causes tectonic plates to separate and move away from each other. (Image credit; Geothermal Education Office, Tiburon, CA)

each other, their continental hitchhikers will get closer together. This is what happened many eons ago when all of the continents that were separated by oceans moved toward each other and fused into one single "super-continent" named Pangaia. When first discovered this strange movement of the crustal plates and their overlying continents was labeled as *continental drift* by scientists, but as the specific underlying geophysical mechanisms involved were clarified it became known as ***plate tectonics***.

Scientists are not sure exactly how early this plate tectonics phenomenon first started on the earth. Scientists have only been able to trace the existence and movements of tectonic plates and their overlying continents back about a half billion years. Some scientists think that the modern day form of plate tectonics, including the creation of the first granite type crustal rocks that allowed the formation of the first proto-continents might not have started on earth until sometime between 3.0 and 3.4 bya (middle Archean). Other scientists believe a more primitive or *proto-tectonic plate* process might have been here by as early as 4.0 bya. However, most scientists now believe that the first modern form of continental land masses containing lighter granite rocks were well on the road to being fully constructed by the end of the Archean Eon. Whereas slightly less than 30 percent of the earth today is covered by land masses, some scientists estimate that by 1.5 bya, continental land masses might have covered as much as 25 percent of the planet. **Figure 4-18** illustrates how our world geography has changed from the Permian Period of the Paleozoic Era a little less than 250 million years ago to the present day. Again, as with the concepts of *light years* and *deep time*, this phenomenon of the "slow" movement over time of the continents is not easy for the author, and perhaps for the reader as well, to intellectually grasp. The continents are presently moving apart at the incredibly slow pace of 5 to 10 centimeters (i.e., 2 to 4 inches) per year. Believe it or not, this pace is even slower than the speed

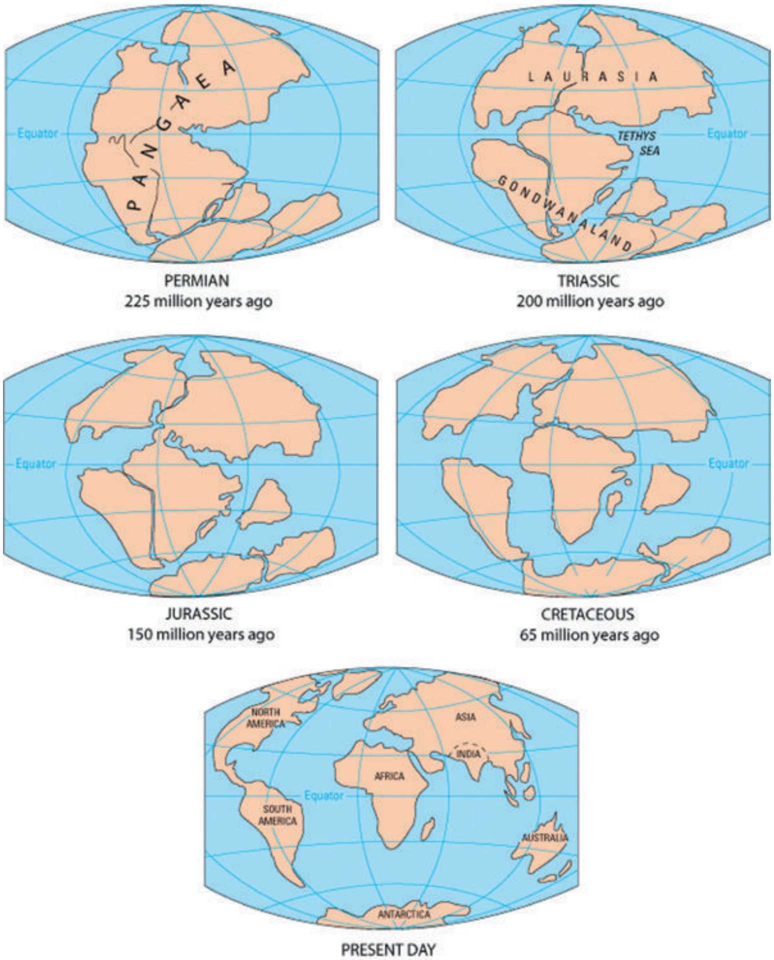

Figure 4-18 -- Illustrates the dramatic shifting of the relative locations of earth's continents that slowly occurred over the past 225 million years. (Image credit: USGS)

with which the author's and reader's finger nails grow. No wonder it took scientists so long to discover (notice?) the evidence for plate tectonics.[6] The reader also should know that this "continental moving thing" has not yet stopped, but will continue well into the future. Approximately 250 million years from now the continents will reverse their direction of movement and all come together once again in a pattern very similar to that of the super-continent Pangaia which existed 225 million years ago. *Historically, the earth's continents seem to have a repeating cycle of coming together and then spreading apart every half billion years.* As I will emphasize later in this chapter, this constant back-and-forth shuffling of the continents was a major player in determining how life on earth developed.

And, as with most things in the natural world, I have both "good" and "bad" news to report regarding this slow continent movement phenomenon. The bad news is that collisions between continental plates produces all those nasty earthquakes, killer tsunamis (undersea earthquakes),

[6]There are two major clues that support the idea that the earth's continents undergo some kind of slow position changes over time. First, if you look at any world map and then visually imagine removing the Atlantic Ocean and pushing the entire eastern coastline of Canada, Greenland, North America, and South America up against the western coastline of Europe, and Africa, the two coastlines will suddenly appear to fit together like two pieces of a jigsaw puzzle. This suggests that sometime in the distant past the two landmasses were joined together as one huge super-continent. The second clue is provided by the finding by paleontologists that the fossilized remains of many of the animals and plants that are found on the continents on either side of the Atlantic Ocean are from the same identical species. Since these critters could not swim, the only possible explanation for their fossilized remains now being so far apart would be if they all lived together on the same combined super-continent ages ago.

and violent volcanic eruptions that mankind has to deal with. And now the good news! First, you might be happy to know that those beautiful mountain ranges (e.g. the Andes, the Rocky mountains, and the Himalayas) you love to climb and ski on are the result of continental plates colliding with each other and shoving some of the rocky materials upward toward the sky.[7] And more good news - ***Plate tectonics, in conjunction with volcanic activity, is the major reason that the earth has managed to have a reasonably temperate climate for so long***. As mentioned above, carbon dioxide (CO_2) is the most common greenhouse gas we have available to assist in regulating our atmospheric temperature. A number of factors will cause the amount of CO_2 to vary in the atmosphere, including plant life, forest fires, and industrial pollution (I will say much more about this issue later in this book). The most common way that CO_2 is removed from the atmosphere, other than being pilfered by plants to carry on their own metabolic activities, is by being absorbed directly or indirectly by the ocean waters. There are two ways in which CO_2 is removed from the atmosphere. First, when rain occurs directly above the oceans, CO_2 will be absorbed from the air and transformed into another type of carbon molecule named carbonic acid and will then be transferred directly to the ocean waters. With the second method, rainfall that occurs over land will produce increased weathering and cause soils and rocks (which have become soaked by the carbon containing carbonic acid) to be washed into the oceans. (Of course, carbon from decaying plants and animals is also washed into the oceans by the same rainwater.) Both sources of carbon then settle to the bottom of the ocean where they are transformed by small marine creatures into animal shells. After the animals die their shells are transformed chemically into carbonate sediments (e.g. carbon-rich limestone and chalk). From there, the carbonate sediments are picked up by the rising lava from convection cells at mid-ocean spreading centers and carried down into the developing subduction zones located beneath the edges of continents. The edges of some continents have mountains containing active volcanoes which then melt the arriving carbonate sediments and release CO_2 gas back into the atmosphere. **Figure 4-19** illustrates the way this extremely important **Carbon Cycle** works.

Thus, the combination of plate tectonics and active volcanism, while providing a very destructive influence on all earth life via natural catastrophes, has provided a very important and long term means of keeping our climate reasonably temperate and life friendly. When the climate becomes warmer, more stormy weather occurs and it rains more. This results in

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[7]Depending on the specific geological and physical forces involved, there are ***three main ways*** in which adjacent tectonic plates can ***crash together*** or ***encounter each other. First***, the two plates can "***hit head-on***" so-to-speak in which the squashed material that is caught between the two plates gets shoved upward to form mountain chains or ranges. This type of collision occurs whenever the two adjacent tectonic plates are very similar in mass (weight). ***Secondly,*** the two plates may, rather than hitting head-on, actually "***side-swipe***" each other (which is what causes earthquakes in southern California and the very recent one in 2010 in Haiti). A ***third effect*** occurs when the edge of a heavier or more massive plate encounters a lighter or less massive adjacent plate. In this case, as depicted in Figure 4-18, the heavier plate actually ***"dives beneath"*** the edge of the lighter plate to create what geologists call a "***subduction***" zone.

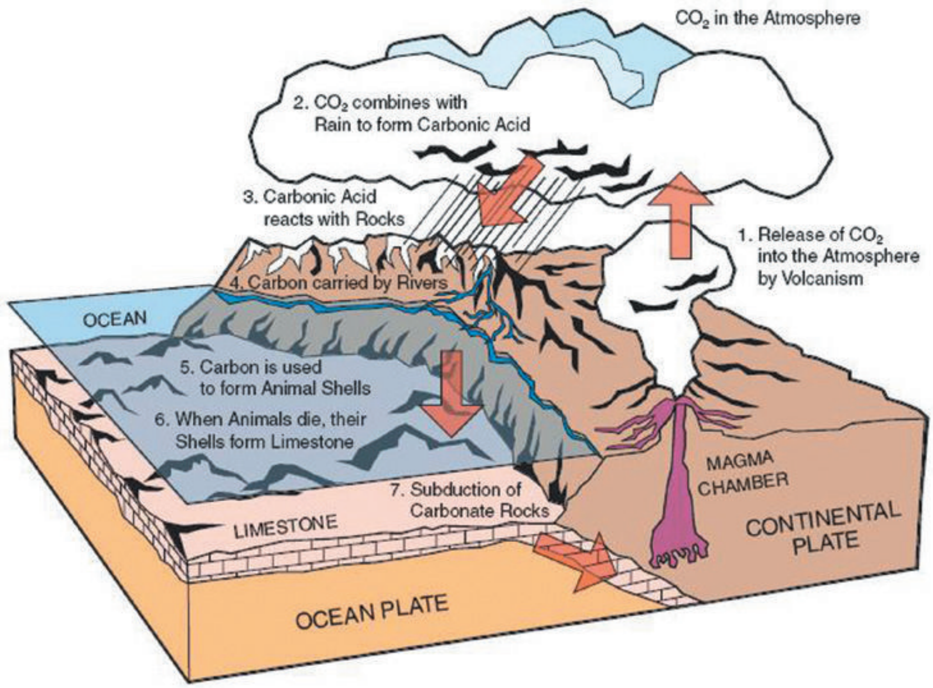

Figure 4-19 - In addition to historically being an extreme nuisance to mankind in terms of causing catastrophic earthquakes, tsunamis, and volcanoes, the process of plate tectonics has been a major benefactor for us. Thanks to plate tectonics and its effects on our weather, carbon containing materials (rocks, sediments, decayed animal and plant parts, etc.) are constantly being recycled back and forth between the ocean floors and the atmosphere. The combination of this carbon cycle and the atmospheric greenhouse effect has allowed the earth to maintain a reasonably temperate climate plus a system for providing a fresh source of carbon for building new life. (Image credit: NASA

increased amounts of greenhouse CO_2 gas being removed from the atmosphere and placed into the oceans. This allows more heat to escape from the earth which, in turn makes the climate cooler. When, however, the climate becomes colder, we have an opposite effect in which it rains less. With little or no rain, less CO_2 is removed from the atmosphere, and this causes the climate to become warmer. It is important to note that the surface air temperatures are not the primary cause of the transfer of the carbonate containing sediments from the ocean floor into the subduction zones located under the continents and then into the volcanoes. This movement of the carbonate sediments is more effected by the amount of remaining heat in the mantle of the earth as well as the activity level of volcanic activity. The levels of the earth's internal heat plus the intensity of volcanic activity were both steadily decreasing during the Archean and Proterozoic Eons, which acted to reduce the rate with which CO_2 was recycled back into the atmosphere. For the past 4.0 billion years, while the amount of heat provided by the sun has been increasing, the amount of heat contributed by the atmospheric greenhouse effect has been decreasing. It would appear, therefore, that these two opposing heating phenomena have achieved some kind of compromise, or as the planetary scientists would more likely call

it, produced another kind of "Goldilocks effect" that has ensured the continued existence of a climate that is not too hot, and not too cold, but just right to foster carbon based life.

However, while the earth's built-in thermostat system seems to be an excellent solution to the problem related to the sun itself not being able to generate enough heat to maintain liquid oceans, it is unfortunately "slower than molasses". If the climate gets too hot or too cold too quickly this system cannot react quickly enough to save the day, so to speak. Scientists estimate that it requires approximately a half million years or more to go through one complete recycling of all the earth's carbon from the air to the oceans and back to the air again. In the remainder of this chapter, as we return to discussing how different life-forms popped up on our planet, we will see that there have been at least five times in earth's history in which sudden catastrophic geological or cosmic events have occurred that produced rapid climatic changes that life could not adjust to quickly enough to avoid major mass extinctions.

Arrival of Oxygen Atmosphere at End of Proterozoic Eon allowed Life to Begin Upgrading to Multi-Cellular Forms

At the beginning of the Proterozoic Eon (which spanned the period from approximately 2.5 bya to slightly more than 500 million years ago), the earth was continuing to develop into a more friendly place for carbon-based organisms to live. The climate, while considerably cooler than it was during the Archean Eon, was still typically hotter than it is today. This general cooling effect was occurring in spite of the fact that the sun, as a normal part of its own evolutionary development, was continuing to gradually get hotter. The rise of plate tectonics, which was well underway by the end of the Archean Eon, was now compensating for the increased solar heating effect by allowing a major reduction in the atmospheric greenhouse effect. Plate tectonics was providing an important means of removing significant amounts of CO_2 gases from the atmosphere and storing it away below the ocean floor. Between the late Archean and the early part of the Proterozoic Eon, plate tectonics in combination with the continual heat-related churning of hot materials in the mantle of the earth had finally allowed the formation of the first true continents. This churning had created a new form of rocky material known as granite that was even lighter (but tougher and therefore more resistant to erosion by ocean surfs) than the rocks contained in the earth's crust. This granite form of rocky material was now beginning to rise above (due to differentiation) and ride on top of the heavier underlying crust to form the continental land masses we are so familiar with today.

At the beginning of the Proterozoic Eon another major environmental change was beginning that would, within a relatively short time (geologically speaking), change the world into a seething biosphere. Remember those residents of the layered stromatolite structures that popped up about 3.5 bya that could use sunlight as an energy source and tossed away oxygen as a metabolic waste product. They had not gone away but had actually flourished. These early

oxygen producing microbes had been busy evolving into additional species of microbes that developed even more advanced and efficient photosynthetic processes. However, between about 3.5 bya and 2.5 bya, while these oxygen producing life-forms were continually pumping huge amounts of free oxygen into the air, virtually all of it was continually being removed from the atmosphere almost as soon as it was expelled by the microbes. In terms of its chemistry, oxygen is an extremely "reactive" element. Oxygen has a very strong natural tendency to form electrical bonds with other atoms.[8] When oxygen combines with other elements, we say the other elements have been "oxidized" (or "rusted"). The early earth contained a very large amount of the element iron (as well as other elements such as hydrogen, carbon, and sulfur that could form molecular bonds with oxygen and thereby provide "sinks" by which oxygen could be removed from the air). When the oxygen expelled by the photosynthetic bacteria came in contact with the dissolved iron, it bonded with it and the oxidized form of iron settled to the bottom of the oceans to form special deposits of iron ore. These deposits of oxidized iron are the source of all the iron that is mined today by man. This iron oxidation saga started shortly after 3.5 bya and reached a peak around 2.5 bya after which it began to dramatically decline. By approximately 1.8 to 2.0 bya, it ended. All of the earth's iron was now oxidized and the oxygen had no place to go and began to rapidly build up in the atmosphere.

While, during the Archean Eon, the earth's atmosphere had been largely a mix of carbon dioxide and nitrogen gases, during the Proterozoic the atmosphere underwent a major transition to being composed of mostly oxygen and nitrogen. The earliest single-cell life-forms (e.g., the prokaryotes) during the Archean, therefore, relied on an anaerobic form of metabolism that did not require oxygen. Although oxygen producing bacteria actually developed quite early around 3.5 bya, it was not until much later, in the middle to latter part of the Proterozoic Eon, that sufficient levels of free oxygen gas became available in the atmosphere to support the aerobic (i.e., one requiring oxygen) form of metabolism that has subsequently become the mainstay for all higher life-forms, including man.

It was also the advent of atmospheric oxygen that allowed the new continental landmasses to become habitable. All stars, including the sun, produce as part of their light spectrum a form of high energy short wavelength light called ultraviolet radiation. This is the part of the sun's light spectrum that produces sunburn and skin cancers, and is the reason we use (or should use) sun block lotions to prevent overexposure to the sun. The form of oxygen that is expelled by cyanobacteria (and plants) is O_2, which is a molecule containing two bonded oxygen atoms. When this form of oxygen reaches the upper atmosphere, it is broken apart by

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[8]Oxygen is second only to fluorine in being the most reactive of all the atomic elements. Oxygen is why exposed fruit (e.g., apples and bananas) turn brown so fast. It is why certain metals, such as iron turn red or "rust" so quickly. It is even why the planet Mars is called the "red planet" (the surface is "rusted"). And, most ominous of all, it is why anaerobic life-forms find oxygen so biologically toxic. Even oxygen breathing organisms like man need to include special chemicals known as "anti-oxidants" in their diets to avoid the ill effects of this extremely toxic element. While we need oxygen to live, too much oxygen will kill us!

the sun's ultraviolet radiation into separate oxygen atoms, some of which then combine with O_2 molecules to form special O_3 molecules (containing three bonded oxygen atoms) called ***ozone***. These O_3 ozone molecules will then absorb ultraviolet rays and convert back to O and O_2, which will then recombine back to O_3 to absorb more ultraviolet radiation. This back-and-forth transition between O_2 and O_3 forms of oxygen molecules effectively acts to Intercept (i.e., absorb) the worst or most destructive portion of the sun's ultraviolet radiation spectrum before it has time to reach the ground and attack the unprotected skin (or genes) of any unsuspecting land critters. The development of the ozone layer at the end of the Proterozoic Eon, therefore, paved the way for life-forms to leave the safety of the oceans and venture out onto the land to begin a whole new line of land-based evolution.

The building of an atmosphere containing free oxygen during the Proterozoic Eon opened the door for the development of much more energetic forms of metabolisms that could support larger and more active life-forms. In contrast to the anaerobic metabolisms used by the earliest prokaryotes, life-forms could now switch to an energy mode that was at least 18 times more efficient. This "energy upgrade" via oxygen metabolism also opened the door for the evolution of a whole new line of larger and more complex single-celled life-forms. The earliest eukaryote forms of single-celled organisms appear to have originated somewhere between 1.5 and 1.8 bya in the first half of the Proterozoic Eon. As described in Chapter 3, these "large" single-cell critters were most likely a merger of different forms of earlier prokaryote forms since many of them seem to house some of these earlier life-forms within their cell walls which have been assigned special duties (e.g., have become *organelles* or *"small organs"*, including mitochondria, chloroplasts, ribosomes, etc.). The eukaryotes are, in a very real sense, the single-cell versions of what would be the next stage of evolution, the future multi-cellular life-forms. The eukaryote form of single-cell organization was now here to stay and all the cells of future multi-cellular life-forms would consist of the eukaryote type of organization.

Finally, toward the end of the Proterozoic Eon or 1.2 bya, the first multi-cellular organisms began to arrive on the scene, consisting of primitive algae (seaweeds) and sponges, followed a short time later (perhaps as early as 1 bya) by more advanced multi-cellular forms such as jellyfish-like organisms. One of these later (lonely) multi-cellular eukaryote prototypes somewhere on the planet developed specialized cells for reproduction and invented ***sexual reproduction***. While multicellularity opened the door to large and extremely complex animals and plants, sexual reproduction opened the door to a much more efficient and productive means of coming up with new and novel ways for genetic variations to be formed, tested, and passed on to successive generations. Whereas the earlier prokaryotes had to wait around for an extremely rare mutation of one of their genes to occur before possibly evolving to a more advanced form of life, each successive generation of sexually reproducing eukaryotes started their lives with a new and unique set of genes, half of which was contributed by each of their two parents. This process of mixing and matching various combinations of genes provided a tremendous advantage in allowing diversification in the species and accelerating the rate

of evolutionary change. For prokaryotes, evolution was slow and boring; for eukaryotes it suddenly got much quicker (and more fun).

Finally, before beginning a discussion of the staggering amount of evolutionary developments that occurred during the last major geological time period known as the Phanerozoic Eon, we need to talk briefly about how the transition to oxygen forms of metabolism created total havoc with respect to the evolution of life on our planet. As has been mentioned earlier, the earliest prokaryote life-forms on our planet that had all developed in hot and oxygen-free environments did not adjust easily to the change in the Proterozoic Eon to cooler climates and oxygen-rich atmospheric conditions. It seems that the severe chemical reactivity of oxygen is a problem for virtually all life-forms including those who need it to fuel their metabolisms, as well as those that do not. During the long stretch of time during the Archean and Proterozoic Eons when oxygen was continually being removed from the atmosphere by iron and other environmental oxygen sinks, those prokaryotes who were extremely "allergic" to oxygen could easily avoid it by simply staying out of its way (e.g., hiding in the bottom layers of stromatolites, or in oxygen free zones of the oceans, etc.). However, huge numbers of other prokaryote species could not avoid it and they perished in what would later come to be known as the earth's single largest mass extinction event (at least so far). The fact that this *oxygen revolution* started relatively early and built up slowly over such a long stretch of geologic time, provided other prokaryote species the time they needed to develop evolutionary strategies (e.g., moving into oxygen free environmental niches) or special protective chemical processes to deal with oxygen's toxic effects. As mentioned earlier, even man has had to develop protective chemistries to deal with the toxic effects of oxygen.

Phanerozoic Eon Sets Stage for Surge toward "Modern Life-Forms"

By the beginning of the Phanerozoic Eon, or a little over 1/2 bya (or 500 million for those readers who, like the author, may consider themselves a bit mathematically "challenged"), the earth had undergone a number of major changes that would now make it more life friendly, at least in terms of how humans today define that concept. Thanks to plate tectonics, the different continental landmasses were here to stay, although they would continue to "drift" and not "stay put". The atmosphere had cooled down (again, thanks to plate tectonics) and had changed from being dominated by carbon dioxide and nitrogen gases to being dominated by oxygen and nitrogen. The advent of free oxygen in the atmosphere, in addition to providing a much more efficient mechanism for extracting energy from organic molecules, had provided an additional benefit in the form of a protective form of oxygen shield (ozone layer) which now protected animals and plants from the sun's most harmful forms of ultraviolet radiation as they began to colonize the continents.

Because of the more life friendly conditions during the Phanerozoic Eon, this period in the history of life saw an extremely rapid increase in the pace of evolutionary developments on

both land and in the oceans. This increase apparently appeared quite suddenly right at the beginning of this most recent Eon or what is known as the Cambrian Period about 550 million years ago. (Please note that, in the remainder of this chapter we will switch to using "**mya**" instead of "millions of years ago", in conformity with our earlier use of **bya** for billions of years ago.) Whenever paleontologists examined rocks of this age or younger almost anywhere in the world, they found convincing fossilized evidence of early multi-cellular life-forms. This sudden and unexpected popping up of extensive numbers and varieties of fossils almost everywhere led the scientists to describe this phenomenon as the ***Cambrian Explosion*** of life. In more recent years, as paleontologists have developed more sensitive tools for identifying fossils, and especially smaller microscopic sized fossils, it has increasingly become apparent that no sudden explosion of life occurred. What happened was that at approximately 550 mya, a large number of different animal species began developing for the first time body parts such as hard shells made of calcium and other bony type structures that are far more likely to be successfully fossilized. Prior to this time, larger macroscopic animals and plants had started evolving but they all had body structures composed of soft tissues that do not fossilize very well. In recent years, using better fossil identification procedures, paleontologists have confirmed that for at least 200 million years prior to the beginning of the Cambrian, an extensive surge (if not actually "explosive" in magnitude) of both microscopic and macroscopic soft-bodied life-forms was well underway. It seems that many of these pre-Cambrian evolutionary developments were natural experiments in which the individual species did not survive for long and vanished from the fossil record before the start of the Cambrian Period. In marked contrast, the explosion of hard-bodied species during the Cambrian Period actually produced all of the 35 or more basic types of body plans (e.g., *mollusks* like clams, oysters, and snails; *arthropods* like insects and lobsters; and *chordates* like humans and fish) that we see subsequently in different species following the Cambrian Period up to the present time. In fact, subsequent evolution has apparently stopped developing any new or innovative body plans and has instead focused mainly on expanding the size and diversity of the basic plans that were already present 500 mya.

However, scientists now believe that the apparent "Cambrian explosion" may have actually been assisted by an earlier catastrophic geological event known as S***nowball Earth***. As mentioned earlier, the earth's continents exhibit a pattern of moving together every half billion years to form combined super-continents. Our last super-continent named Pangaia occurred approximately 225 million years ago. About 750 million years ago, another super-continent named ***Rodinia*** was present which was just beginning to break up. For at least 350 million years prior to the breakup, this huge super-continent had been very dry since most of its total area was quite distant from any surrounding ocean waters. As a result, very little rain-related weathering was occurring and the climate remained quite warm. However, once the super-continent broke up into many smaller portions of land surrounded by nearby ocean waters, it became much wetter. Increased rainfall began to remove CO_2 greenhouse gases from the atmospheric which caused the climate to suddenly begin getting much colder. This triggered

the absolute mother of all ice ages. The entire planet plunged into an extreme deep freeze that caused glaciers from both the north and south poles to form and extend, according to a few scientists, all the way to the equator. The earth was virtually covered all over by ice caps that may have been a mile or more thick in many locations. This resulted in the massive extinction of most species of sea life worldwide. Eventually, increased underwater volcanic activity and release of CO_2 greenhouse gases back into the atmosphere warmed the planet, melted the global ice caps, and "saved the day" (so-to-speak). The "Cambrian explosion" was, therefore, likely facilitated by the freeing up of environmental niches all over the world by this snowball earth episode that new animal species could begin evolving into and exploiting.

Before describing the final stages of the ascent to mankind, the author needs to discuss one additional very important evolutionary change that occurred during the Cambrian Period that many scientists believe set the stage for the rapid diversification of animal life plus the development of nervous systems and intelligent behaviors. During the Cambrian some primitive sea creature somewhere invented the compound eye.[9] Animals (whether ocean or future land critters) now could rely on a sensory system that was far more efficient than smell or touch in allowing them to rapidly and effectively cope with and adjust to sudden changes in their surrounding environments. The coming of eyeballs allowed life-forms everywhere to make the transition from a passive (i.e., bumping into, or following their noses) mode of obtaining their next meal to a predatory lifestyle which required multiple physical and behavioral skills (size, strength, cunning). This resulted literally in a "warfare" or competition style mode of survival in which both the hunters and the hunted had to quickly and effectively develop better and more efficient means of getting something to eat or avoid being eaten. In addition to sex and oxygen, this predatory thing provided by far the greatest enhancement to the future evolution of complexity and diversity that life had encountered in its 4+ billion year history. In fact, it is probably the rise of predation that indirectly facilitated the so-called Cambrian explosion of life since both the hunters and hunted alike needed to develop hard "fossilizable" body parts (sharp teeth for the hunters, protective outer shells for the hunted) in order to survive. Unfortunately, as will be discussed in Chapter 7, mankind's having evolved directly from predatory ancestors may have instilled in him a strong genetic predisposition for aggressive behavior which, if not controlled or changed, could lead to our self-destruction before we are able to reach for the stars.

The sudden and dramatic surge of evolutionary developments that occurred in the Phanerozoic Eon from a little less than 550 mya to the present can be characterized as a much faster paced addition of new "firsts" in terms of the addition of new species of life-forms in the continuing saga of life. Unfortunately, there have been many more "firsts" than we can

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[9]The extreme importance of the development of eyesight to the future evolution of both ocean and land-based animal life is attested to by the fact that eyeballs have been re-invented at least five times in five separate lines of evolution. Man's eyeball, while it serves our purpose, is not even the most "efficient design" that evolution has come up with.

possibly list here[10], but the reader has ready access to a huge professional (and popular science) literature that can provide this information. At the end of this book, the author has listed two excellent books (Johnson & Stucky, reference 15; and Liees et al., reference 17) that I personally found to be very useful and informative but not overly detailed. The reader may wish to again review the *Cosmic Calendar* and *Figure 4-1* presented at the beginning of the present chapter for a brief listing of the particular "firsts" that I selected for discussion in the present book.

Over the next 500 million year history of the earth following the Cambrian Period, life proceeded to rapidly advance in terms of diversity, complexity, size (physically large or giant critters would before long begin popping up everywhere), and sheer bulk (population census numbers). In fact, scientists tell us that this unusually productive period in the history of earth life was the high point of evolution. After that time, and continuing to the present, life has actually been on the decline worldwide. During the Paleozoic Era following the Cambrian Period, the presence of continental land masses plus a protective oxygen ozone layer in the atmosphere opened the door to the colonization of land by both plants and animals. The plants arrived first followed shortly thereafter by primitive animals. The first plants to develop included the algae, fungi and lichens followed by the first primitive trees and the beginning of forests. The first land critters to arrive included the ancestors of today's millipedes, scorpions, and spiders. Because of the presence of warm, lush, and oxygen-rich environments in which to live, some of these early insect-like critters (like their later dinosaur successors) were able to grow very large by today's standards. Some dragonflies had wing spans of over two feet, and one early millipede achieved lengths of 6 feet or longer. Following the primitive insect species came the first amphibians and then, after that, the first reptiles. And, as we will shortly see, the earth's exceptionally life friendly environment at this time in history also proceeded to make giants out of some of the later arrivals. **Figure 4-20** shows an artist's drawing of what the Earth may have looked like during the earlier part of the Paleozoic Era. Starting with the

Figure 4-20 - Presents an artist's view of what the earth probably looked like during the early Paleozoic Era about 400 million years ago. While primitive plants and the first trees had been here for awhile, animals were just beginning to crawl out of the oceans and colonize the land. The two animals shown at the bottom of the drawing are examples of early amphibians (or "tetrapods") that still resembled fish as much as land critters. (Image credit: Walter Myers)

[10]Experts in the field, while not agreeing on the exact numbers, have estimated that the total number of living species (whether single-celled, e.g., prokaryotes or eukaryotes, or multi-celled, e.g., plant or animal) that currently exist on earth is somewhere between 10 and 100 million. More sobering is the estimate that of all living species that ever lived on earth, 95 to 99 percent are now extinct.

Figure 4-21 - Artist's view of early earth during the Carboniferous Period of the late Paleozoic Era (about 300 million years ago). This was the high point of plant life on earth. Dense forests were found everywhere from the north pole to the south pole. (Image credit: Walter Myers)

Carboniferous Period about 370 mya, because of a warmer hothouse type climate, combined with high oxygen levels and still somewhat high carbon dioxide levels (due to continuing high levels of volcanic activity) in the atmosphere, thick forests and swamps, with extensive vegetation, began developing all over the planet from the north pole to Antarctica (**Figure 4-21**). This Carboniferous vegetation "explosion" is one of the sources of those nasty fossil fuels (coal) that currently enable the world's economies, threaten international peace, and keep some of us awake at night with global warming fears. During the Carboniferous, the land continued to be dominated by amphibians and reptiles that were continuing to grow bigger. Meanwhile, back in the oceans, critters were also getting large and more prolific due to our planet's increasing life-friendly conditions. While the first small primitive fish had developed about 500 mya in the late Cambrian Period (which with their backbones are the most primitive ancestors of the body plan leading to man), sea life was also now rapidly increasing not only in size, but also diversity and complexity.

The short Permian Period (which extended from slightly less than 300 to 250 mya), that followed the lush and highly prolific life friendly Carboniferous, is known by scientists as the time of the ***Great Dying*** since it came close to witnessing the end of all life on earth. During this time, all of the earth's continents combined together to produce a single super-continent named ***Pangaia***. The Permian Period, while dominated on land by amphibians and reptiles, lush jungles and even some deserts, plus prolific oceanic environments filled with all sorts of living creatures, ended with the most severe of the five major mass extinction events in which close to 96% of all marine life and 70% of land species on earth were extinguished. The exact cause or causes of this major mass extinction is still being debated by scientists. There is evidence that this extinction may have involved more than a single calamity with as many as possibly three separate events occurring over a period of up to 10 million years.

Severe volcanic activity was very likely the major cause. A huge geographic area in what is now Siberia was suddenly hit by an absolutely devastating series of volcanic eruptions that scientists call ***mantle plume*** eruptions. Mantle plume eruptions are the most powerful type of volcanic activity known to geologists. They are millions of times more powerful that the Mount St. Helen's volcano that erupted in Washington state in 1980. These types of eruptions occur when an absolutely gigantic ball of hot molten lava in the mantle rises to the earth's surface and simultaneously triggers eruptions from thousands of separate volcanoes that are scattered over a huge geographical region. This particular volcanic event is believed to have resulted in an area about the size of the modern continental United States being covered by the equivalent of 1000 foot deep lava flows. To make things even worse, some scientists now estimate that these mantle plume eruptions may have occurred repeatedly over a period as long as a million years.

In addition to significant increases in air temperatures caused by the release of greenhouse CO_2 gases into the atmosphere by the volcanic eruptions during this great dying event, many scientists believe that the resulting heating of the ocean waters by the hotter atmosphere would have greatly increased the magnitude of the disaster by also causing the release of huge quantities of methane gas into the atmosphere. The warmer oceans would have proceeded to thaw out deep sea sediments that contained frozen water that had methane gas trapped or dissolved inside. Since methane gas is also a greenhouse gas, this would have added to the greenhouse effect already being produced by the CO_2 gases from volcanic activity. This "one – two punch" combo of CO_2 gases being pumped into the atmosphere followed by methane gases would have produced a combined global warming effect that would have been lethal to most forms of life. Finally, a few scientists have also speculated that an impact from a large asteroid or comet might have also occurred that added a third "punch" to this already horrific destructive period in life's history.

However, in spite of the near total extinction of all life that occurred at the end of the Permian Period, life came back stronger (plus bigger and meaner) than ever during the next three Periods (Triassic, Jurassic, and Cretaceous) of the Mesozoic Era (which is known as the "age of the reptiles"). During the early part of the Triassic Period, the first dinosaurs and the first primitive mammals both made their appearance. Because of warm tropical weather conditions plus lots of oxygen to breathe, and plenty of plants and animals to eat (plus few predators big enough to threaten them), the dinosaurs exploded in size and proceeded to spread all over the world. Figure **4-22** shows an artist's drawing depicting how truly massive the dinosaurs had become by the end of the Jurassic Period. And, while the prolific Mesozoic Era was spawning huge dinosaurs on all of the continents, the equally life friendly oceans were answering back with their own large terrifying sea "monsters" (**Figure 4-23**).

The dinosaurs would rule as the world's dominant form of land life up until approximately 65 mya when the "sky would literally fall on them". Since the beginning of the Phanerozoic Eon, there have been five major extinction events in which some cosmic or geologically-related catastrophe has acted to cause the relatively sudden demise of a large percentage of different

Figure 4-22 - The Mesozoic Era, from about 250 to 65 million years ago is known as the reign of the dinosaurs. This artist's drawing shows a typical scene from the latter part of that time period when dinosaurs had attained their maximum size. The large long-necked animal in the center of the picture was able to grow up to 60 feet long and weighed as much as 15 tons. (Image credit: Karen Carr of the Karen Carr Art Studio)

Figure 4-23 - Huge dinosaurs that roamed the ancient countryside during the middle Mesozoic Era were not the only monsters on earth. The oceans also contained ferocious meat eaters that were very close in size, and sometimes larger, than today's more gentle whales. (Image credit: Walter Myers)

life-forms on earth. While we have little solid geological or other kinds of evidence to identify the exact causes of most of the earlier extinction events, we do have fairly good evidence of what caused the extinction of the dinosaurs approximately 65 mya. An asteroid (or possibly a comet), thought to have been somewhere between 6 and 10 miles in diameter, which is estimated to have been equal in size or volume to Mount Everest, slammed into the northern coast of the Yucatan peninsula in the Gulf of Mexico (**Figure 4-24**). That this extinction event was primarily caused by an asteroid or comet impact and not some other kind of sudden extreme weather-related or geological event is provided by two pieces of evidence. First, scientists

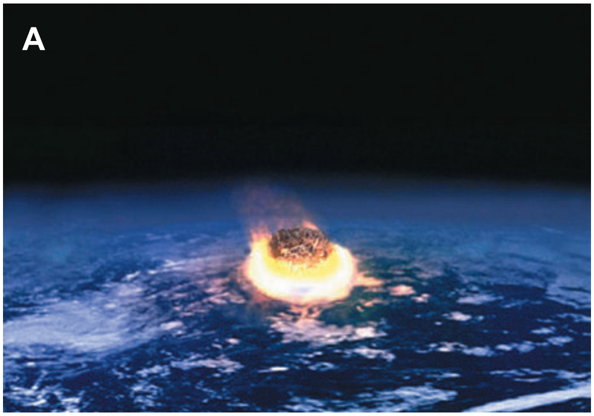

Figure 4-24 - An artist's conception of the asteroid impact that struck the earth approximately 65 million years ago that triggered a global catastrophe that ended the long reign of the dinosaurs. **A** shows an artist's image of the asteroid striking the earth (Image credit: NASA), while **B** shows an artist's drawing of what doomed dinosaurs all over the world might have seen as the skies filled with huge amounts of hot debris falling back to the surface (Image credit: Joe Tucciarone)

have identified the existence all over the world of a layer of sediment (that ranges from a half inch to well over three feet in thickness) at the same level below ground that contains ash from forest fires plus a special type of metal called *iridium* that, while rare on earth, is quite common in interstellar space. Most scientists now believe this rare metal could have only come from the exploding asteroid itself. In addition, the remnant of a 112 mile wide crater has been found on the northern coast of the Yucatan peninsula that has been determined by radioactive dating to be approximately 65 million years old. This asteroid, which was moving at a speed 60 times that of a rifle bullet (approximately 45,000 miles per hour) when it struck the earth, may have produced the explosive energy equivalent of 100 million hydrogen bombs, which created a world-wide disaster.

The asteroid impact may have produced, over much of the North American continent, the equivalent of a magnitude 13 earthquake (the San Francisco earthquake of 1906 was a mere 7.8 level on the Richter scale used by geologists to measure the intensity of earthquake activity). Gigantic tsunami generated tidal surges that could have been as high as between 300 and 500 feet in height likely devastated vast regions of what is now the western, central, and eastern continental United States plus areas as far away as New Zealand and Antarctica. In addition to immediately destroying virtually all plant and animal life within a radius of 5,000 miles, the impact threw huge amounts of hot and melted debris into the upper atmosphere that spread all around the world. As the extremely hot debris reentered the atmosphere it triggered massive forest fires all over the world. Worse yet, a vast cloud of dust and smoke particles filled the upper regions of the atmosphere world-wide that blocked the sun for four to six months plunging the entire world into almost total darkness (except for the light from nearby burning forests). The

lack of sunshine, in addition to producing near freezing temperatures, also virtually stopped all growth of new vegetation and began severely disrupting the world's food chains. While the dust and smoke particles were largely removed from the atmosphere after six months, the sun did not start shining again for another two to three years.

The worst of the catastrophe, however, was just beginning! Unfortunately, the asteroid had impacted in a part of the world that had a very large amount of sulfur-bearing minerals buried underground. The asteroid not only threw huge amounts of dust, smoke, and debris into the atmosphere but also huge amounts of rocks and soils containing sulfur. This sulfur immediately bonded chemically with the oxygen in the atmosphere to produce huge quantities of a very nasty type of gas called sulfur dioxide (SO_2). Even though the smoke and dust debris in the atmosphere was, after six months, beginning to settle back to earth, the SO_2 remained in the atmosphere for another two to three years. The SO_2 now took over the role vacated by the smoke and dust of blocking the sunlight and keeping the earth in a near freezing state for almost another three years. Finally, the SO_2 began to be washed out of the atmosphere by rain waters. Unfortunately, this event itself created a new round of problems for the surviving plants and animals since the SO_2 now fell to the ground as "acid rain" containing huge quantities of sulfuric acid that proceeded to burn the leaves off plants and poison any surviving animals' water holes. Thus, over a period of almost four years following the asteroid impact there was a slow but steady killing of most plants and animals larger than that of an alligator, including the dinosaurs.

Unfortunately, this was again not the end of the story with regards to this extinction event. The massive forest fires plus damage to both life and the oxygen atmosphere had also inflicted a major shock to the earth's normal carbon cycle. Suddenly, the earth's atmosphere would have contained excessive amounts of CO_2 that would now trigger increases in the world's greenhouse effect that would last for possibly another 100 years. Many parts of the world probably suffered from as much as a 20 degree increase in average surface temperatures during much of the next century.

Finally, while most scientists believe the asteroid or comet impact event was the major cause of the demise of the dinosaurs, others note that the population of dinosaurs had already begun to decline, perhaps as a result of over-population or disease-related factors. One theory suggests that the recent creation by plate tectonics of a land bridge (i.e., Central America) between North and South America had allowed lethal forms of bacteria to be transferred between the two previously isolated dinosaur populations causing disease outbreaks. Also, at about the same time as the dinosaur extinction event, the earth was undergoing yet another round of severe volcanic eruptions that was centered in what is now known as the Deccan Plateau region of West Central India. These eruptions occurred almost continually over a period of close to 30,000 years and involved a geographic area that was more than twice the area of present day Texas. In addition to producing extensive lava flows with depths as great as several hundred feet in many locations, these volcanoes were located in an area of the world that contained

high levels of sulfur minerals below ground. These volcanoes spewed huge amounts of sulfur dioxide gas into the air that, in high concentration levels, would have been deadly to any nearby animals as well as vegetation (due to the creation of sulfuric acid rains) . Volcanic activity of this extent and magnitude could possibly have contributed to the total dinosaur casualty count produced by the asteroid impact.

DEATH OF DINOSAURS OPENS DOOR FOR "AGE OF MAMMALS" AND EVOLUTION OF HUMANS

Whatever the cause of the dinosaurs' demise, most scientists today believe it opened up environmental niches all over the world which our early mammalian ancestors were only too willing to move into. The demise of the dinosaurs gave way to the new age of the mammals. During the next 65 million years or so, the mammals would come to dominate the earth. Like the dinosaurs, these new tenants of the earth would take full advantage of the vast resources that the co-evolution of life and Earth had passed their way. The presence of a temperate environment filled with lots of invigorating oxygen to breathe plus, dare I say it, sex, would now allow our mammalian ancestors to diversify, grow bigger (i.e., the era of the giant mammals), and, according to a few experts, possibly a bit smarter. This "changing of the guard" from dinosaurs to mammals, however, was slow in getting started. In addition to the first primitive mouse-sized mammals having the misfortune of arriving on Earth at the same time as the first dinosaurs, they were also forced to live in the same environmental niches with their huge neighbors. In order to keep from being stepped on or eaten by the dinosaurs, the small completely defenseless mammals had to live in underground tunnels until the dinosaurs finally departed this world. Then the mammals were finally free to come out of their underground hiding places and begin growing, diversifying, and expanding to all corners of the globe.

Early in the Cenozoic Era during the Eocene and Oligocene Epochs (i.e., 12 to 25 mya), the giant mammals started arriving on the scene. Two varieties of such large mammals developed - the hunters and the hunted. One group took advantage of the huge expanses worldwide of a new type of plant called "grass" and became the first primitive horses, cows, deer, and other so-called grazing herbivores. The other group were the large carnivores (dogs, tigers, bears, etc.) which now preyed on the hapless (but not defenseless, remember speed and cunning are important to both the hunters and the hunted) herbivores.

Geologically speaking, the transition from the first primate-like ancestors of man to man himself occurred very rapidly. The first primitive monkeys appeared about 30 to 40 mya followed by the first apes around 15 mya. The first true ***hominids*** originated sometime between 5 and 8 mya. These ape-like creatures, while having an ape-like body plan and gait, began to exhibit the beginning stages of a "big head" with enlarged cranium and larger brain. Finally, during the Pliocene Epoch, about 5 mya, the environment in Africa began to undergo changes

from a forested woodland to a more open and savannah type landscape, which forced man's hominid ancestors to leave the trees. Now that they were in the open and more vulnerable to large cats and other predators, they had to rely heavily on an upright mode of walking (and running) in order to be able to see their enemies before they got close enough to threaten them. For many years, paleontologists had believed that it was the transition from living in trees to living in open treeless savannahs that triggered upright walking in the hominid line of evolution. It was thought that the first truly erect walking/running hominids did not develop until a little over 3 million years ago.[11] However, the recent discovery of a new species of hominids named **Ardipithecus ramidus** that apparently lived in Ethopia about 4.4 mya has totally turned the paleontology world upside down with respect to the issue of when and where erect walking was developed. "Ardi", as this new species has been nicknamed by paleontologists, lived in a forested area and not an open savannah. He lived in trees. It was not surprising, therefore, to find that this creature, as do all modern tree-living primates, had prehensile big toes on his feet that assisted him in climbing and moving about in trees. However, when they examined his pelvic bones the paleontologists were astounded to find that Ardi was not a knuckle walker like modern apes and chimpanzees but actually walked erect like modern humans. The discovery of Ardi suggests that not only did our hominid ancestors have the capacity for erect walking a full million years earlier than previously thought, but **erect walking may not have been triggered by our ancestors leaving the trees to live in open treeless environments**.[12] A few scientists have, however, more recently challenged this conclusion so the final chapter of this story may not have yet been written.

The first truly modern human species, ***Cro-Magnon*** man is thought to have developed in Europe about 180,000 years ago. Until approximately 30,000 years ago, Cro-Magnon man had competition in the form of a second very closely related human species called Neanderthal man who had probably originated a little before 250,000 years ago. Whether Neanderthal man was a separate species from Cro-Magnon man is still being debated by scientists. While Neanderthal man was somewhat larger and bulkier in build, both species had developed a primitive social and tool-making culture and both probably had primitive language skills. Neanderthal man was not the club wielding "monster" caveman type that Hollywood has subsequently portrayed. Whether the two groups could successfully interbreed is not known

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[11]"Lucy" is the nickname given to the first almost complete fossil of what was previously believed to be the first hominid species that began walking erect after coming down from the trees. Lucy and her fellow Australopithecus afarensis colleagues lived in East Aftrica from about 3 to 4 mya. She was apparently an adult but only a little over three feet tall.

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[12]How or when this upright walking/running thing developed, however, is not nearly as important to man's history as the fact that this uniquely human mode of locomotion also freed up our ancestor's hands which had been previously developed as a sophisticated grabbing and manipulation tool to assist in swinging through the trees. Those newly freed and quite sophisticated five-fingered manipulators could now be used by the developing brain to make tools and eventually to perform brain surgery.

but present evidence indicates that none of Neanderthal man's genes exist in modern man suggesting they did not (or could not). It appears that Cro-Magnon emerged victorious in this competition somewhere around 30,000 years ago.

To complicate the lives of the first humans and their immediate hominid ancestors, around 2 mya the *ice ages* arrived on earth. There is considerable disagreement among scientists as to the exact causes of ice ages. Many scientists believe the ice ages are the result of cooling effects produced by long term alterations in the tilt of the earth's axis of rotation, as well as possibly the periodic movement of our solar system through more dust-filled regions (i.e., spiral arms) of our Milky Way galaxy that slightly attenuate the light output from the sun. Other scientists believe that a possible cause for ice ages might be the disruptions of the normal north-south ocean currents that sometimes occur when the different continents are shuffled around by plate tectonic movements. Over the next two million years and continuing up to the present and extending into the future (Earth's most recent ice age is still with us) the planet would undergo periodic cycling between warmer and cooler time periods. The cold periods of each ice age cycle would last anywhere from 40,000 to 60,000 years. About 10,000 years ago the earth began entering its most recent inter-glacial period which is still with us today. Thus, in the early years of modern man's existence on earth (from approximately 180,000 to 10,000 years ago), the climate remained unstable which probably contributed to man's continuing lifestyle as a hunter-gatherer (**Figure 4-25**). At the beginning of the most recent interglacial period, about 10,000 years ago, our human ancestors had finally developed sufficient social and technical skills (e.g., tool making) that they finally chose to take advantage of the arrival of a stable warmer period to settle down in one spot and make a go at planting and harvesting plants to supplement their meat diets. The planting of the first seeds into the ground transitioned the human species into a whole new non-nomadic lifestyle now based on agriculture, and later animal breeding and husbandry. Human civilization had been launched on earth, and the rest is now history.

Figure 4-25 – Early man not only had to deal with the misery of the ice ages, but also the dangers of being a hunter-gatherer. A predatory lifestyle does not mean that brains will always win out over brawn. (Image credit: Libor Balak)

Role of "Mass Extinctions" in Evolution of Life

Before, in the next chapter, turning to an in-depth discussion of where astrobiologists will be searching for evidence of extraterrestrial life, I need to list and discuss the most common types of hazards or threats that might prevent life on any exoplanet from surviving long enough to possibly evolve to a more intelligent form. In spite of the amazing beauty and peaceful aura of the nighttime sky, astronomers tell us that the universe is an extremely hostile environment and contains a myriad of powerful physical phenomena that could instantaneously wipe out all life on any single planet (see Phillip Platt reference 19 at end of book). Thus, one more factor that scientists will need to take into consideration when designing searches for extraterrestrial life will be to limit such searches to environments that are relatively safe in the sense that no major environmental or cosmic dangers exist that could threaten the long term continuation of life, once started. As described in earlier sections of the present chapter, life on earth had to successfully navigate itself through a series of at least five major threats to its continued existence and, even today, dangers still exist. Some of these threats were, and still are, capable of actually destroying all life on earth, while others have the potential to inflict widespread global damage of a sufficient magnitude that entire species or ecosystems could be eliminated, including even knocking human civilization as we know it "back on its heels" for a very long period of time.

Unfortunately, while life may have existed on our planet for as long as 4.0 billion years, the only mass extinction events we have any reasonable amount of information for are the ones that have occurred in just the past half billion years. Because of the tumultuous nature of normal ongoing geological and other natural forces, no direct or even indirect physical evidence (geological, chemical, or fossil) for any such events that might have occurred earlier has survived to the present day. Scientists believe that many kinds of destructive events were both more frequent and potentially more catastrophic for any early life during the Hadean and Archean Eons, but have probably decreased in severity with time. Other forms of potential extinction events are, unfortunately, as much a threat today as they were four billion years ago. The two basic kinds of dangers that earth experienced and which most exoplanets would likely encounter are ***external threats*** in the form of destructive forces that originate from outer space and ***internal threats*** due to the large numbers of constantly changing interactions among the planet's own geophysical, heat-related, and climatic processes. While these internal changes are frequently slow and mild enough to be tolerated by life via its evolutionary adjustments, they may sometimes be rapid and destructive enough to inflict major damage to individual species or entire ecosystems. In the following pages, however, we will quickly learn that these two types of extinction events are definitely not mutually exclusive since external events (e.g., asteroid or comet impacts) can directly cause internal events such as outbursts of severe volcanic activity or extreme climatic changes. The author will next briefly describe each of the known forms of specific threats that scientists believe occurred on earth, and which could again occur on earth

as well as other habitable exoplanets in the universe. For those readers interested in obtaining more specific information related to the details of the five major mass extinction events that occurred on our planet, I have listed (at the end of this book) two published books (T. Hallam, reference 11; and A.H. Knoll, reference 16) that readers will find useful but not too technical.

Table 4-1 summarizes the essential features of each of the five major extinction events that occurred on our planet, along with an estimation of the total percentages of marine and land life that may have been killed during each episode. The reader needs to know, however, that while there is good agreement among scientists as to when each of the extinction events occurred, there is considerably less agreement as to exactly how severe each event was in terms of the exact percentages of marine and land life that was killed. Most scientists agree, however, that any event that involves a global kill rate of 25% or more is quite severe, and that the Permian-Triassic extinction, which was the most severe of all, came very close to snuffing out all life on Earth for keeps.

Table 4-1 -The five major extinction events that almost destroyed all life on primitive earth

CRETACEOUS-TERTIARY (K-T) Extinction: *Occurred about 65 million years ago (mya). Was probably the result of the impact of a 6 to 10 mile wide asteroid or comet that landed in the Gulf of Mexico just off the northern Yucatan Peninsula. It destroyed 50% of all land animals worldwide plus about 40% of marine life. This event eliminated the dinosaurs and opened the door to the evolution of mammals and eventually man. Some researchers believe that additional severe volcanic activity plus overpopulation or disease related factors may have contributed to the extinction of the dinosaurs.*
END OF TRIASSIC PERIOD Extinction: *Occurred approximately 200 to 215 mya. This extinction was probably caused by the splitting apart of the super-continent Pangaia that created the opening of the Atlantic ocean. Severe and widespread volcanism was triggered that led to deadly global warming. Approximately 25% of marine life was killed worldwide along with many larger forms of land life, including amphibians and some of the newly evolving dinosaurs.*
PERMIAN-TRIASSIC Extinction: *Occurred about 250 mya and was the most severe extinction event to date (labeled by paleontologists as the "great dying"). An estimated 96% of all marine life plus 70% of land species were destroyed. Some scientists believe a comet or asteroid impact might have been involved although severe widespread volcanic magma flooding activity (originating from what is today the Siberian Artic region) was probably the primary cause.*
LATE DEVONIAN Extinction: *Occurred roughly 360 mya as a series of successive shorter term events, for which the cause(s) are still unknown. Approximately 60% of marine species were destroyed.*
ORDOVICIAN-SILURIAN Extinction: *Occurred about 440 mya and is believed, by some scientists, to have been the result of a gamma ray burst emitted by a distant supernova stellar explosion in our galaxy. The ozone layer was destroyed for a period of five years which triggered an ice age and the destruction of up to 60% of all mar*ine life.

Most Common Forms of External Threats to Evolution and Survival of Life on Planets

External threats to life on any habitable world are those catastrophic physical events that originate directly from or in the vicinity of other celestial objects in regions close enough to planets that they can have a dramatic destructive effect on life itself or the geological

Figure 4 -26 - The possibility of large asteroids or comets wandering in from the outer regions of our solar system and striking the earth is still a very real threat to life on our planet. **A** shows an artist's drawing of a large asteroid approaching earth (Image credit: Joe Tucciarone), while **B** depicts what might happen if NASA was unable to divert its path in time to avoid a collision with earth (Image credit: NASA)

and climatic support systems that are critical for life. The good news is that, because of the vast distances between any habitable planets and their closest celestial neighbors, all but the most profound threatening sources would be located too far away to do anything more than put on a colorful show for any alien astronomers' cameras. The five major extinctions that challenged life's existence on earth during the most recent half billion year period were each separated by time intervals ranging anywhere from approximately 50 million to almost 150 million years. In contrast, the heavy bombardment period of the Hadean Eon and early parts of the Archean Eon probably had such events occurring at intervals as close together as a few thousand years (or possibly less).

With respect to external threats to the survival of life-forms anywhere in the universe, the most common are impacts or collisions between habitable planets and other orbiting objects (e.g., meteors, asteroids, comets, or leftover debris from the planetary accretion process) that happen to share the same planetary system (**Figure 4-26**), as well as explosions of dying stars (supernova events) located relatively close (i.e., too close) to the planetary system. While suspicious that comet or asteroid collisions might have possibly been involved in some of the earlier extinction events on our earth, scientists are only reasonably confident of the role of such an event in the most recent episode that 65 million years ago resulted in the demise of the dinosaurs and the subsequent rise of man. Some scientists believe that many of the earlier mass extinctions might have involved impact events, either alone or in association with internal events (severe volcanic outbreaks or subsequently triggered climatic changes). It is noteworthy that the primary cause of the death of the dinosaurs was not the impact itself but the severe internal events (global wildfires, acid rains, long term blockage of sunlight which produced

near-freezing temperatures and breakdown of vegetation-based food chains, etc.) that occurred for several years following the impact.

While an unlikely event, it is possible that large asteroids or comets could, as happened 65 million years ago, again in the future produce another major worldwide loss of life or even a complete and total destruction of the entire planet. While virtually all astronomers recognize the very serious nature of this potential danger, very little in the way of preventive actions have been undertaken to make sure this calamity never happens. The U.S. Congress, however, was apparently aware of this continuing danger from the skies when, in 2005, it issued a mandate to NASA that this agency, by the year 2020, develop a program that would be able to successfully detect and catalogue 90 percent of all such threatening objects in our solar system that were large enough (defined as .6 miles in diameter or greater) to inflict worldwide destruction and loss of life. NASA now classifies any such objects that are this size or greater as **N**ear **E**arth **O**bjects or "NEOs". Unfortunately, as of the writing of this book (2010), no presidential administration has requested, nor has any congress allocated the funds that NASA would need to meet the requirements of this congressional mandate. Since getting hit by a NEO is itself a worldwide concern, it would seem reasonable to make paying for it an international responsibility. If detected far enough ahead of time, our scientists now have the technological means of sending unmanned spacecraft to intercept such NEOs and either physically or gravitationally altering their orbits sufficiently to keep them from striking the earth.[13]

However, while the primary objective for any NEO protection system will be to provide a means of protecting the earth from the very worse or global-level impacts, there is an additional quite serious need for such programs to be expanded to protect us from the much more likely and frequent smaller asteroid or comet impacts that could destroy entire cities. In 1908 a much smaller asteroid, *which is estimated to have been considerably smaller than .6 miles in diameter*, exploded in the air over a very remote and unpopulated part of Siberia. Virtually all vegetation and wildlife was destroyed in an area estimated to have been as large as 900 square miles. This asteroid, while not as destructive as the one that killed the dinosaurs, could have destroyed a city the size of modern day Moscow, London, or Washington, D.C.

With respect to external threats, next in frequency behind impact events are the so-called ***gamma ray bursts*** (GRBs) that are commonly associated with supernova explosions of massive stars. GRBs were discovered accidentally during the Cold War with Russia when the U.S. military launched special satellites into earth orbit to monitor for the release of gamma rays produced by Soviet nuclear bomb testing. Following the signing, in 1963, of the *Nuclear Test Ban Treaty,* the U.S. military was concerned that the Russians might attempt to secretly continue such tests. The U.S. satellites did, in fact, begin detecting the presence of gamma rays. However, their origin seemed to be more from the skies rather than the ground behind the Iron

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[13] The last thing NASA should try to do would be to "blow up" a NEO using some kind of explosive device. Converting a single large NEO into a whole truckload (train load) of smaller NEOs would very likely increase the amount of destruction on the earth.

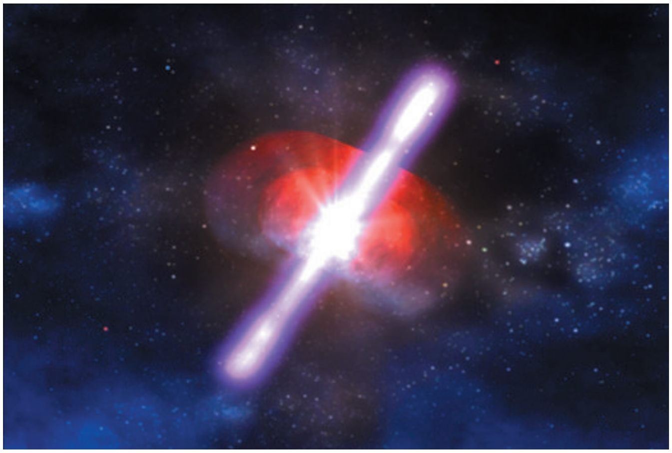

Figure 4-27 - An artist's view of what a gamma ray burst associated with a supernova stellar explosion might look like close up. (Image credit: NASA)

Curtain. We now know that GRBs are relatively common occurrences. While the frequency of supernovas are thought to vary widely from galaxy to galaxy, scientists estimate that in a typical galaxy like our Milky Way, we can expect on average somewhere between two and five such events per century. When a giant or super giant star explodes, incredibly intense but relatively narrow beams of gamma rays are shot straight out into space at close to the speed of light from both the north and south poles of the star (**Figure 4-27**). If a planet of any stellar system is located directly in the path of either of the two GRB beams and, at a relatively close distance (anything less than 5 - 6 thousand light years is considered by most astronomers as probably "dangerously close"), it will be hit by the beam with devastating consequences. The inhabitants (the seeing and knowing ones) of the planet will not notice anything unusual except that a new extremely bright star will suddenly appear in the sky. If the GRB arrives at night, the star may even be brighter than the full moon - if it arrives during the day, it will seem as if an extremely small but bright second sun has suddenly appeared out of nowhere.

The gamma rays from the incoming GRB will, depending on their strength and the distance of the supernova, partially or totally destroy the protective oxygen ozone layer of the planet's atmosphere. The destruction of the ozone layer would then allow the planet's home star to once again begin bathing the entire surface (and any unprotected animals or plants) with deadly ultraviolet radiation. This would set into motion long term and devastating chain-reaction types of destruction of most of the exposed life-forms located on any continental landmasses, and over the next several years most exposed life would vanish. Ocean life too would be badly hit. The base of the ocean's food chain, i.e., the planktons, would, because they live so close to the ocean surface, be totally zapped by the sudden onslaught of deadly ultraviolet radiation triggering a catastrophic collapse of the world's underwater ecosystems. A few critters, similar to earth's own prokaryotes that might live deep underwater or far below the planet's land surfaces, might possibly survive to again jumpstart a new round of evolution. Over the next millions or billions of years (following the return of a viable ozone layer), the tenacity of nature's evolutionary process could possibly allow the return of simple and advanced life-forms but in a form that would likely be totally different from what existed before the GRB catastrophe.

Fortunately for us, while GRBs are believed to occur in our Milky Way galaxy on average once every 20 to 50 years, the probability of our planet (or any planet) being in the direct path

of a GRB beam from a close-by exploding star is so low that this type of catastrophe would probably only occur about once or twice every billion years. However, scientists at NASA and the University of Kansas, led by A. Melott and B. Lieberman, have recently proposed the idea that a GRB may have hit the earth about 440 million years ago between the Ordovician and Silurian Periods of the Paleozoic Era, causing the first of the five major mass extinctions. A giant star 15 times or more massive than the sun, located in a region of our galaxy possibly as far away as 6,000 light years, may have exploded sending a GRB our way that hit us at that time. The passage of the GRB would have lasted no more than 10 seconds[14] but it could have resulted in a near total destruction of our protective ozone layer that lasted for at least five years. Since most life at this time was confined to the oceans, only surface or near-surface ocean life (e.g., planktons) would have been affected. This, however, may have produced a ripple effect in the food chain that resulted in the destruction of at least 60 percent of the deeper and larger forms of sea life as well. A severe ice age phenomenon is also believed to have been associated with this extinction event. In addition to destroying the ozone layer, the GRB beam could have caused the creation of huge quantities of nitrogen dioxide, a gas similar to the smog we frequently see in today's polluted cities, which would have blocked the sun and produced freezing temperatures.

Common Internal Threats to Evolution and Survival of Life on Planets

In addition to external threats associated with asteroid or comet impacts, or gamma ray bursts associated with exploding stars, other major extinction events could be triggered solely by internal factors such as widespread volcanic outbreaks plus intense eruptions of isolated super-volcanoes. The early earth contained much more internal heat than it does today and was far more susceptible to "blowing its top" so-to-speak via sudden surges in volcanic activity. Scientists believe that outbreaks of severe volcanic activity were a major contributing factor in each of the three most recent mass extinction events. In addition to intense volcanic activity likely being the greatest contributor to the Great Dying event of the late Permian Period (about 250 mya), many scientists believe that intense volcanic outbreaks might have also been involved in the late Triassic extinction event that occurred about 200 mya early in the dinosaurs' reign. The breakup of the Pangaia super-continent that occurred at that time is thought to have produced a new rift in the crust (birth of the Atlantic Ocean) between the North American and

[14]While the primary damage to life from a GRB would be the result of long term exposure to ultraviolet radiation produced by the destruction of the planet's ozone layer, the short 10 second long exposure to gamma rays would itself produce lethal effects for any exposed life-forms. Gamma rays are the same deadly radiation that is produced by atomic bomb explosions. While the two atomic bombs dropped on Japan in WWII each immediately killed close to a hundred thousand people, over the next several years many thousands more died from radiation sicknesses induced by exposure to the gamma rays themselves. A similar scenario would occur following a GRB event.

Africa/Asian tectonic plates that triggered an absolutely catastrophic outbreak of extensive and intense volcanic activity. And, of course, many scientists believe that intense volcanism, while not being the major player in the death of the dinosaurs 65 mya was probably a significant contributing factor. Therefore, it is likely that young worlds located elsewhere in the universe would also be vulnerable to these same kinds of internal heat related threats.

While volcanoes were, in earth's early history, generally far more frequent and more violent than they are today, they have always exhibited a very wide size range. Although today's volcanoes, because of the reduced internal heating of the planet, occur more infrequently they can still be a major local threat to cities and human populations that are located nearby. One form of volcano, commonly referred to as the *super-volcano* can today still pose a significant global threat to life. Today, only a small handful of such extreme volcanoes exist worldwide. Such super-volcanoes were, however, far more common in earth's earlier history. The last such super-volcano eruption (Mt. Tamboro) occurred in April of 1815 in the Indonesian Ocean. This volcano erupted with a force estimated to have been somewhere between 100 and 150 times more powerful than the more recent Mt. St. Helen's eruption in Washington State in 1980. This super-volcanic eruption was so intense that it produced what historians call t***he "year without a summer"***. The amount of dust, ashes, and other debris that was thrown into the upper atmosphere was sufficient to significantly block the sun's rays worldwide. This event caused a dramatic drop in average surface temperatures that was similar, but not quite as intense, to what happened during the dinosaur extinction event. While the sunlight blockage effect started in April 1815 and extended until the early part of 1817, the atmospheric dust clouds did not drift as far as America and Europe until several months following the volcanic eruption. For a large portion of the world the 1816 summer agricultural growing season did not happen. The summer of 1816 was wet and cold, and many of the summer crops totally failed.

Another major super-volcano is located beneath Yellowstone National Park in the United States. It consists of an incredibly large underground magma chamber, or so-called *caldera*, that measures 32 by 45 miles. This volcano has a history of erupting approximately every 600,000 years. The last eruption occurred 640,000 years ago. If this caldera were to explode at full force, it would totally devastate much of the continental United States and produce a worldwide catastrophe (freezing temperatures, destruction of vegetation-based food chains along with entire animal and plant ecosystems) that would last for many years. **Figure 4-28** depicts the potential threat of this super-volcano in Yellowstone National Park.

As mentioned above, many of the common internal threats to life's survival (e.g., intense volcanic outbursts, or ice-age like episodes caused by blockage of sunlight by debris clouds thrown into the atmosphere by volcano eruptions or asteroid impact events) are themselves secondary to preceding external events. However, early in their post-accretion histories, many planets are likely to be internally unstable due to excess and relatively poorly controlled geophysical and climatic-related energy sources. Our own earth was, during much of the Hadean and Archean Eons, a seething hotbed of violent volcanic activity and outgassing of

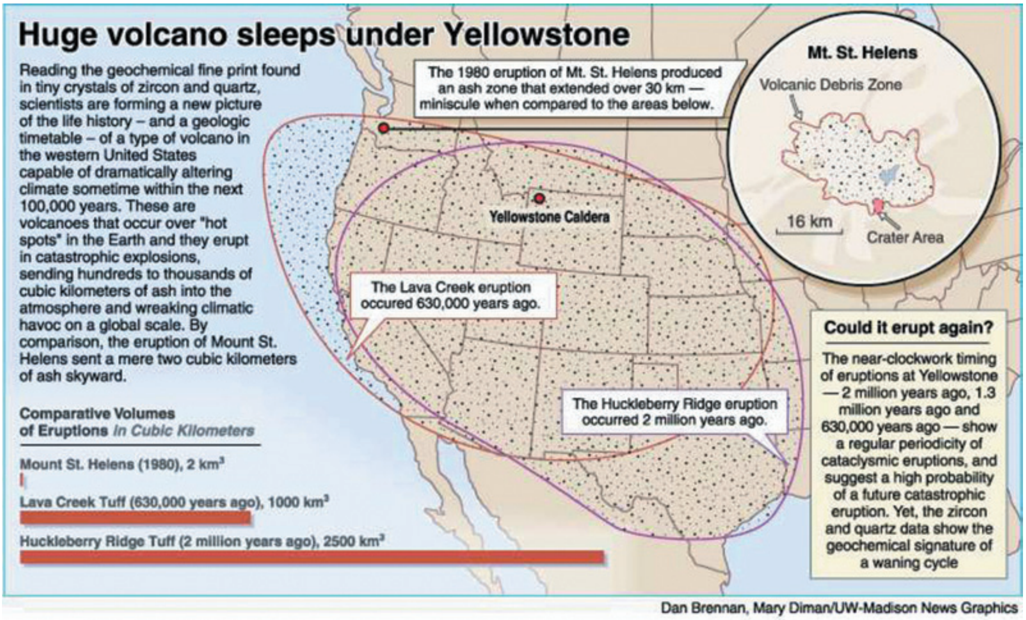

Figure 4-28 - Illustrates the magnitude of the potential threat that the Yellowstone super-volcano may pose for the future of life on earth. The lighter and darker pink regions show the extent of the severe volcanic dust and debris fallout from each of the last three major eruptions of this volcano. Note, shown in red in the upper left corner, the small size of the ash field from the 1980 eruption of the St. Helens volcano. (Image credit: University Communications, University of Wisconsin-Madison, Copyright UWM Board of Regents)

various kinds of gases from its interior that had been planted there by the intense celestial pounding that the earth experienced during the accretion and subsequent heavy bombardment periods. Our own solar system also had to deal with an earlier cooler sun that made it difficult to establish a long term stable habitability zone. The sun, even today, is continuing to get hotter, which means that this instability will continue on into mankind's future (or whatever life-forms may replace us). Therefore, episodes of having to tolerate excess climatic heat alternating with ice-age cold spells were probably a virtual way of life for our earliest primitive ancestors. As described earlier, sometime around 750 million years ago, huge numbers of our ancestors froze to death when the earth's CO_2 thermostat control system allowed the earth's temperature to plunge to the point that glaciers from both polar regions may have reached almost as far as the equator. This catastrophe created all kinds of empty environmental niches in the world's oceans that may have left the door wide open for the subsequent "Cambrian explosion" in life's evolutionary saga.

Although no scientist (and that includes the author) would ever label any extinction event as "good" or "bad" with respect to opening doors for new life to evolve, many scientists today would likely support a form of the old adage that "what does not kill you makes you better". While over the course of life's history on earth, mass extinction events (probably including many more than just the five big ones we know of) while contributing to the elimination of well over 95% of all species that ever lived, have also been the primary factor that made it possible

for life to continue evolving and becoming increasingly more diverse and complex. In the next chapter, I will turn to a discussion of how and where our astrobiology friends and their planet hunting cohorts will begin their exciting search for the products of the universe's evolutionary "soup kitchens". While it is entirely possible that life "as we know it", especially those life-forms that self-proclaim themselves to be highly intelligent, may indeed be rare in the universe, the unbelievable vastness of a universe filled with the possibility of huge numbers of habitable worlds, combined with science's increasing optimism related to the tenacity of the evolutionary process, has this amateur astrobiologist very excited. While the carbon-based forms of life we earthlings are familiar with might, or might not be common in the universe, other exotic kinds of Life based on other kinds of complex chemistries may also exist, and might even outnumber us. ***However, before turning to a discussion of the search for extraterrestrial life, the author absolutely must spend some time describing some additional threats to mankind's future which, unlike natural extinctions, are always "bad". These threats are very real and very serious, and, unfortunately, are a direct consequence of man's occasional less than intelligent solutions to his problems or needs.***

Will Mankind be the Source of the Final Mass Extinction of Life on Earth?

After the invention of nuclear weapons during WWII, it quickly became apparent that mankind had finally managed to develop the ultimate means of self-destruction. The proliferation and rapid growth of the power of nuclear weapons, combined with mankind's incessant "tribal warfare" mentality (I.e., the Cold War) placed us on the brink of being able to terminate all life (at least surface life) on our planet by simply (accidentally or deliberately) pushing a series of small buttons. The end of the Cold War, instead of eliminating this threat, has only heightened it. While, during the Cold War, the American and Soviet military machines did have some technology in place to safeguard against man's worst fears of a sudden uncontrolled unleashing of a nuclear holocaust, the post Cold War era has left us with many of the nuclear weapons still armed, cocked, and ready for Immediate launch. And now we do not even have safeguards against this happening since such weapons could come under the control of irresponsible third world governments or be stolen by terrorists hiding in caves. And, unfortunately, the proverbial "genie is now out of the bottle" for keeps. Even if the Russians, Americans, and other nations that currently possess these weapons were to destroy every last one of them, mankind now has the technological know-how that could easily allow rogue countries or wealthy well-connected terrorists to build their own. Therefore, "mass extinction by nuclear means" is still very much a threat to the continuation of life on planet Earth, and must continue being a top concern for all governments and citizens until it is totally eliminated.

In addition to the possibility of mass extinction via the unleashing of nuclear weapons, the post WWII era has also handed mankind yet another major threat to the future of life. Our compulsive intelligent nature has now provided mankind the means by which we could inadvertently or deliberately inflict mass extinction via biological weapons. Thus, irresponsible third world dictators or terrorists could now kill us with either dirty nuclear bombs or biologically altered microbes or chemical agents. This bioterrorism threat must also be taken very seriously by all governments and citizens until it too is totally eliminated.

At several points in the present book, the author has also mentioned that mankind is currently facing a possible *global warming* crisis that many scientific experts believe has the potential to possibly trigger a runaway greenhouse effect that could destroy all life on our planet, or at least make our environment miserably hot and our climate totally unfriendly. Now that I have, earlier in this chapter, covered much of the basic information needed to understand this potential threat, including the role of the earth's carbon cycle in climate control and the role of plate tectonics in regulating atmospheric concentration levels of greenhouse CO_2 gases, I will now present a detailed summary of the specific nature of this threat.

Ever since primitive man learned to burn wood (and other combustible materials) using fire, he has been contributing to the creation of CO_2, which is the predominant form of greenhouse gas in Earth's atmosphere. As we saw earlier in this chapter, the presence of atmospheric greenhouse gases is the major reason life was able to develop and flourish on our planet. Without CO_2, our planet would be far too cold to allow the existence of liquid water which is critical to us carbon-based life-forms. For many thousands of years following his discovery of fire, the total amount of CO_2 that man created was virtually nil in comparison to other natural sources of CO_2 (volcanoes, forest fires, the respiratory waste-product of man and other animals, rotting of dead plant and animal life, etc.). However, beginning with the so-called Industrial Revolution in the mid-1700s, this situation changed drastically. Man began burning not only wood, but other forms of fossil fuels (coal, oil, natural gas), but this time to *build, build, build*, and not just cook and keep warm. Man learned how to build larger and larger machines to do his work faster and more efficiently. He started building large homes and even larger factories, all of which demanded huge amounts of energy. He quickly discovered that wood and fossil fuels were the easiest and quickest source of readily available energy, even though excess amounts of smoke and heat were undesirable by-products. Since CO_2 is a major ingredient of smoke, man's new smoke stacks were now not only stinking up the air, polluting his lungs, and irritating his eyes, but also pumping huge amounts of greenhouse gas into the atmosphere. Once the Industrial Revolution started it quickly grew and grew and, within a short time every major city became a smog-shrouded nightmare with huge volumes of sticky black soot clinging to everything.

The atmospheric greenhouse effect itself was not discovered until 1824 by Joseph Fourier, and it was not until 1896 that another scientist named Seante Arrhenius discovered that CO_2 was the major gas that was responsible for creating this effect. By that time, the Industrial

Revolution was in full swing in every major industrialized country in the world. By the late 1800s man's compulsive nature had finally allowed him to be able to accurately measure and keep records of daily surface temperatures all over the world, and also precisely measure the relative amounts of CO_2 in the atmosphere as well as the amounts of CO_2 being pumped into the skies from his smoke stacks (plus in a few more years by his combustion engines). However, it was not until well into the 20th century that man began to wake up to the possibility that the combination of industrialization, CO_2, and the greenhouse effect might not make for such a good mix with respect to man's future.

Starting in the second half of the 20th century and continuing up to the present day (2010), some scientists and concerned citizens began to notice a number of changes in the world's climate and environment that gave them cause for concern. The first major anomaly was the observation that starting around 1900, the global mean surface temperature started rising at a surprisingly fast rate. In the 100 year period between 1905 and 2005, the average world surface temperature increased by an average of 0.9 degrees Celsius or 1.6 degrees Fahrenheit (**Figure 4-29**). During this same period, the amount of CO_2 in the atmosphere rose by a total of 35% (**Figure 4-30**). While an average temperature increase of just over 1.6 degrees F in one century does not sound like much, climatologists tell us that, in terms of the relative magnitudes of worldwide geophysical events, it is ***huge***. The CO_2 level in the atmosphere measured in 2005 is the highest it has been in the past 650,000 years. What is even more alarming is the fact that, at the present rate of increase, the world's average surface temperature could

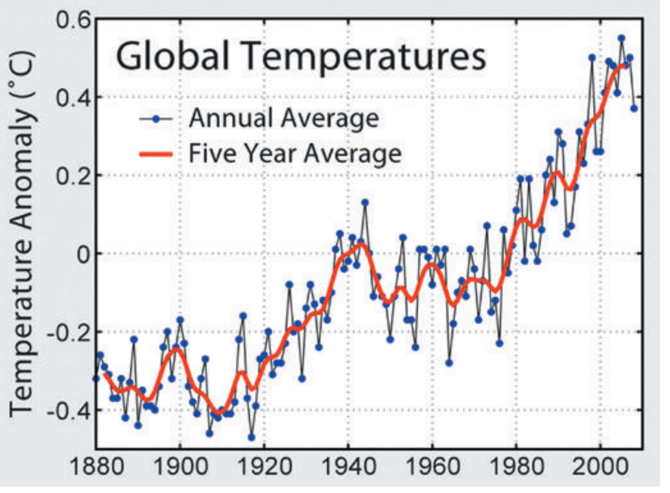

Figure 4-29 – Shows the dramatic rise in the earth's average atmospheric temperature that began following the year 1900. (Image credit: NASA)

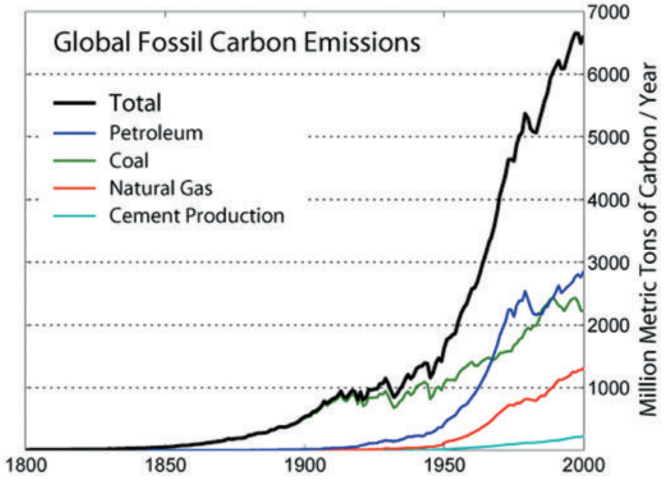

Figure 4-30 - Illustrates the dramatic rise in the atmospheric concentration of CO2 greenhouse gases beginning with the advent of the industrial revolution. (Image credit: Mark Thorpe/Wikipedia Commons)

rise by as much as another 7.2 degrees Fahrenheit (4 degrees Celsius) by the end of the 21st century. What would be the major consequences of such a worldwide temperature increase? Climatologists tell us that, while the effects would be widespread and generally severe, it would be very difficult to draw any kind of accurate predictions of how specific effects would vary in different locations around the earth. As any weatherperson will tell you, day-to-day or month-to-month changes in the earth's regional climate patterns are difficult enough to predict with current technologies, but predicting effects a hundred or more years from now is virtually impossible. If severe global warming becomes a reality in the next century, we will likely not be able to easily draw definite cause-and-effect relationships between specific weather events and the global warming phenomenon. Most regions of the earth would suffer while others might, at least initially, actually benefit. Regional changes in the amount and pattern of precipitation may completely redo the map of the world in terms of flooding and drought zones. Both Africa and Western Europe would probably be thrown into incredibly severe drought conditions while Canada, due to a climatic warming trend caused by global warming might actually incur an agricultural "boom" due to warmer and wetter conditions and become the world's new "bread basket", at least for awhile. The snow covered winter zones of the earth would drastically shrink, glaciers everywhere would melt at a rapid rate and the North Pole's ice cover would disappear and Antarctica would eventually become a dry wasteland (or an inland ocean due to rising sea levels). The loss of snow and ice worldwide would further exacerbate the global warming effect by decreasing the amount of sunlight that could be reflected back into space (less light would be bounced back into space by the rapidly shrinking snow and ice areas while more sunlight would be absorbed by the less reflective but now more extensive ground and ocean surfaces). Of course the fact that ice and snow areas worldwide would start melting and shrinking would produce rises in sea levels everywhere. In fact, such dramatic rises in sea level have already begun (**Figure 4-31**). Between 1900 and the year 2000, the worldwide average sea level has already risen by 7.8 inches (20 centimeters). Again, this may not sound like much, but scientists tell us that, taken as a worldwide average, it is ***huge*** (and definitely not insignificant). By the end of the 21st century, some scientists predict that sea levels worldwide may rise as much as another 2.6 to 6.6 feet (.8 to 2 meters). This rise in sea levels is largely due to the rapid melting of glaciers worldwide (**Figure 4-32**), as well as the shrinkage of the

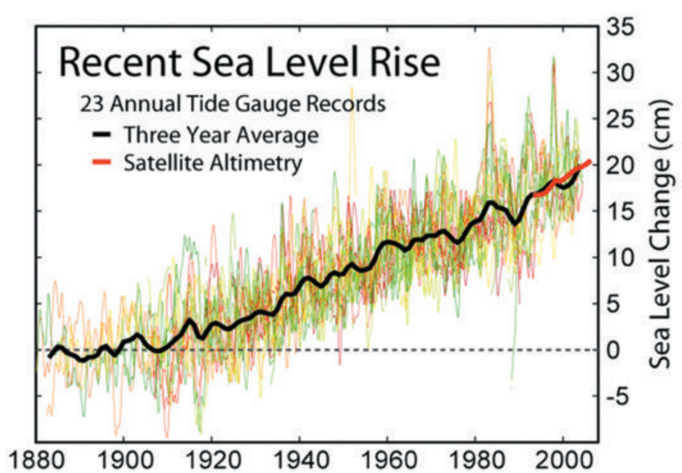

Figure 4-31 - Illustrates the dramatic rise in the earth's average sea levels shortly after 1900. (Image credit: Bruce Douglas/Wikipedia Commons)

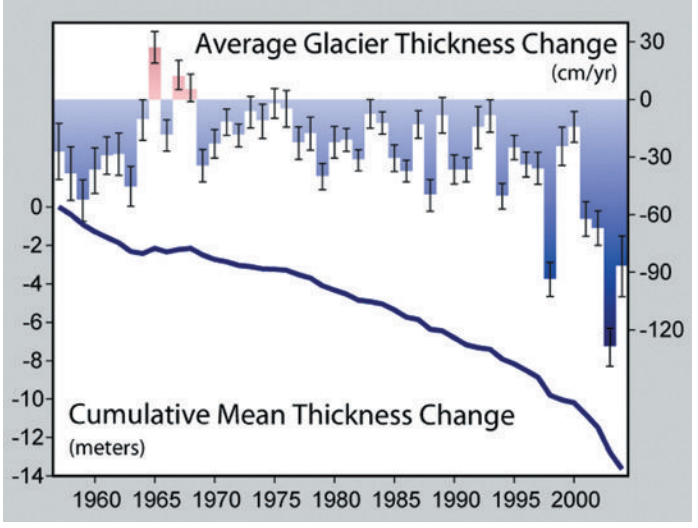

Figure 4-32 - Shows the sudden dramatic decrease in the average thickness of glaciers worldwide that has occurred since 1960.(Image credit: Robert Rohde/Wikipedia Commons)

ice-covered north and south polar regions. The rapid shrinkage of the ice cover at the North Pole now has the scientists at NASA very concerned. **Figure 4-33** shows the dramatic magnitude of this effect in space photographs taken only 23 years apart. The Greenland ice cap which has been very stable in size for many eons, is also beginning to rapidly melt. If this dramatic loss of our ice and snow covers continues, the loss of coastal areas and low-lying areas worldwide, such as the American gulf coast and Holland, for example, will cause an economic, sociological, political, plus human nightmare scenario as entire populations will have to be displaced further inland. Global warming will, *and probably already has*, caused warmer ocean temperatures and more severe hurricanes and typhoons worldwide. The author, who lives in New Orleans and is a Katrina survivor is now a diehard "believer" of such dire predictions.

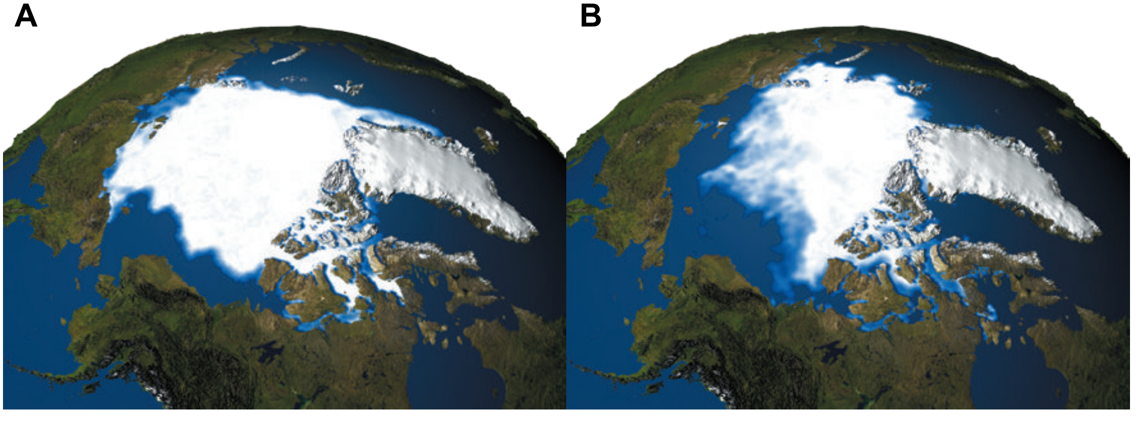

Figure 4-33 - NASA satellites took identical photographs (at exactly the same time of year and day plus same angle and distance) of the Artic icecap in (**A**) 1980 and again in (**B**) 2003. The dramatic shrinkage in the size of the icecap that apparently occurred in just 23 years motivated the NASA scientists to issue a special "alert" message to the world that something might be amiss with respect to the world's climate. (Image credit: NASA)

Of course, not every expert accepts the possibility that mankind is headed toward a major catastrophe brought on by global warming. However, the evidence continues to grow that this type of disaster may lie in our future unless we take immediate steps to cease our dependence

on fossil fuels and switch to use of alternative clean energy sources. Many scientists strongly believe that the earth's carbon cycle (and plate tectonics), which has for so many years allowed CO_2 levels to be controlled sufficiently to allow life to flourish, cannot be quickly turned on or off. If mankind stopped all usage of fossil fuels by 2050, it would still require several thousand years for airborne levels of CO_2 to return to the levels that existed worldwide prior to 1900. The author sincerely believes that switching to clean energy alternatives is absolutely a "no-brainer". Fossil fuels are dirty and inefficient, dangerous to our health and, whether we like it or not, will all be burnt up (or too inaccessible to be economically viable) within one or two hundred years, anyways.[15] The severity of future global warming effects may not be as bad as many present doomsday scenarios predict, but they definitely will not be good either.

However, one of the worst fears that a few scientists have expressed is that the continuing rise of CO_2 in the atmosphere might turn out to be the proverbial "straw that broke the Camel's back" with respect to eventually triggering the worst case scenario of a runaway greenhouse effect. A runaway greenhouse effect is what occurs when a planet's natural temperature regulating (thermostat) system gets completely swamped causing the surface temperature to begin rising in a totally uncontrollable fashion. The CO_2 greenhouse effect is not the only source of global warming that is occurring. The sun, itself, due to its natural evolution, is continuing over time to very slowly get hotter and hotter. And, as mentioned above, as the planet gets warmer and warmer, the resulting loss of ice and snow coverage on the surface causes more and more of the sun's light to be absorbed rather than being reflected back into space. Thus, the combined effects of the sun getting hotter, plus more sunlight being absorbed due to loss of reflective ice and snow, plus man's pumping more CO_2 into the air, may eventually turn out to be more than the Earth's thermostat system can handle. In the next chapter, I will describe what some scientists believe might have been a similar runaway greenhouse event on the planet Venus that was triggered as a result of this planet's being slightly closer to the sun than is the Earth. Whether we like it or not, the natural tendency of all stars, including our sun, to gradually get hotter during their normal lifespan will eventually trigger a runaway greenhouse type phenomenon. While, for our home planet, this absolutely normal and unavoidable "act of nature" should not occur for another five billion or so years from now, a few scientists fear that, if mankind does not switch to clean energy, this doomsday scenario could happen much sooner.

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[15]As I sit in front of my computer this afternoon working on this book, my home town of New Orleans, LA and the entire surrounding American gulf coast is being threatened by yet another "demon" related to man's addiction to fossil fuels. A huge oil drilling platform located off our coast exploded and sank to the bottom of the Gulf of Mexico on April 20, 2010. A little over 100 days later the gushing oil well was finally plugged but not until a total of over 200 million gallons of crude oil had been unleashed that will badly cripple one of the world's single largest seafood industries for many generations to come. Yet another reason for mankind to get their act together and switch to clean energy alternatives!

CHAPTER V

THE SEARCH FOR OTHER WORLDS AND OTHER LIFE-FORMS

In Chapter 2 of this book, we learned that our scientists now believe we live in a universe that is not only incredibly vast but also now appears to support large numbers of planetary systems which could potentially be home to some form of life. In Chapter 3, we further learned that in spite of the fact that our home planet is absolutely teeming with life virtually anywhere and everywhere we look, one and only one biological form of life exists and that one is based on water and the carbon atom. While trees, flowers, the birds and bees, whales, bacteria, and man look incredibly different they all are only small variations on the same basic theme of *life as we know it*. Finally, in Chapter 4 we learned that, in addition to being extremely tenacious in being able to spring up in all kinds of seemingly hostile environments, life on our planet also exhibits an uncanny ability to be flexible and adaptable in adjusting to all but the most devastating changes in the environment in which it lives. If we were to ask our scientists what this single example of what appears to be a remarkably resilient form of life on earth might imply for the possibility of life elsewhere in the universe, they would undoubtedly respond that, while life on our own planet is definitely widespread and incredibly diverse, it is still the only place in the universe that science has thus far been able to search for the possible presence of life. Because they are trained to be ultra-conservative, scientists are always extremely reluctant to draw conclusions from a single observation (or, as they call it, an "***N of 1***"), no matter how strong that single observation may appear to be. However, thanks to the recent rise of computers and the space age, our scientists now have the technology that they need to begin increasing the size of their ***N*** by actually looking for extraterrestrial life. Most scientists agree that finding life in only one other location in our own solar system (e.g., Mars) and thereby increasing the size of their data base (number of observations) to an ***N of 2*** would definitely turn the odds in favor of life being , if not universal, at least more than an extremely rare fluke of nature. In the present chapter, the author will tell the exciting story of how our astrobiologists are now beginning to seriously tackle this profound question of whether life is common or uncommon in the universe.

What kinds of Extraterrestrial Life-Forms should we Search For?

Our life scientists now have a very good idea of what kinds of chemical, physical, and environmental factors are required to foster life on planet Earth. Whether this is the only type of life that is possible or is but one of many alternative formats that life could follow is, at present, totally unknown. We have absolutely no knowledge of the existence of life anywhere else in the universe. Therefore, for obvious practical reasons, our scientists must, at least initially, limit their searches to looking for life-forms that are similar to those that currently inhabit our own planet. ***Therefore, our scientists now firmly believe that our initial searches for ET should be strictly focused on looking for evidence of carbon-based life-forms.*** (In the remainder of this book, I will sometimes refer to the "search for extraterrestrial life" as the search for "ET" with appropriate apologies to Steven Speilberg for stealing his famous movie character's nickname.) On Earth one atomic element and one atomic element only has assumed the role as the dominant chemical ingredient for all life -- and that element is ***carbon***. While some atomic elements are completely unable to form any chemical bonds with other atoms (i.e., electrically link together to form molecules), and most can only form weak bonds with one or two other atoms at once, carbon has the uncanny ability to form strong and stable electrical bonds with as many as four other atoms at one time. The strengths of the bonds that carbon is able to form are very life friendly in terms of being "just right" (i.e. not too strong nor too weak) to easily permit carbon atoms to make new chemical bonds with other elements when needed plus also protect any bonds from being broken when they should not be. This allows carbon to assume the role as the "backbone" for the huge varieties of large and complex macromolecules that are critical for life. There is only one other atomic element that comes even close to carbon in having this multi-bonding capacity and that is *silicon*. However, while silicon can also bond with as many as four other atomic elements at one time, the bonds are frequently unstable. Silicon bonds are sometimes too strong to be quickly and easily broken when required by a given biological chemical reaction or process, or too weak to allow them to be resistant to premature or accidental breakage. Silicon cannot, therefore, easily form and maintain stable biotic macromolecules that require long chains and/or side-chains of simpler molecular units. This explains why astronomers, when studying the chemical makeup of interstellar gas and dust clouds, find lots of simple molecules containing silicon and oxygen (e.g., SO_2 or silicon dioxide), but no evidence of large macromolecules involving long chains of silicon combined with other elements.

So, at least on Earth-like planets, the carbon atom would seem to be the best choice as the primary or dominant chemical element necessary for life. Another critical requirement for life on earth is the presence of some form of *medium* or environment in which biologically important molecules can physically reside that allows them to physically make contact with each other in order to chemically interact and form new or different molecules. If the molecules were wandering around in a rarefied gaseous medium (e.g. the atmosphere) they would tend

to be too far apart to easily get together and interact quickly enough. If they were located in a thicker or more solid medium, such as rock or ice, they might be considerably closer together but would not be able to move easily and make contact. On Earth, liquid water seems to be the ideal medium since it allows molecules to be close enough and move easily enough to readily interact. Water is also an ideal *solvent* which allows certain materials to dissolve and go into solution which is also important for life-related functions. This is why all living cells are filled with a watery gel-like substance and the contents of the human body is approximately 62 percent water. On earth, the combined heat of the sun and the continuous atmospheric greenhouse effect has acted to maintain water in a liquid state. Water also has another important advantage over other kinds of liquid mediums since the temperature range that is needed to maintain it in a liquid state (from 32 to 212 degrees Fahrenheit) is wide enough to help protect life from those unavoidable random climatic temperature fluctuations that most planets probably incur over time. Finally, water in contrast to all other forms of liquid mediums (e.g., ammonia, methane) has another unique chemical quirk since it tends to become less dense when it freezes. This allows ice to float on top of water which helps to prevent the oceans from freezing all the way to the bottom. This provides a safe refuge for sea life to escape to under all but the most severe environmental cold spells. Some scientists believe that other volatile materials such as ammonia or methane, which are able to remain in a liquid state under much colder conditions than found on earth, might be able to serve as a liquid medium or solvent to support some other forms of life. ***Therefore, our scientists also believe that if we limit our initial search for ET to looking for evidence of carbon-based life-forms similar to those found on earth, we must also search for the presence of extensive amounts of liquid water that is needed to support this form of life.***

Another critical feature of earth's environment is its "ideal" temperature. Our planet, thanks to many variables, including distance from the sun, the atmospheric greenhouse effect, and the interactions between plate tectonics and the subsurface heat sources seems to be able to maintain a "just right" temperature for life. Carbon-based chemistry (at least as we know it) is quite heat sensitive. If it gets too cold, metabolic chemistries may slow up too much to maintain life. If too hot, molecular bonds may get torn apart when they should not, our proteins may begin to resemble scrambled eggs, and life may come to a halt. ***Thus, in searching for ET, our scientists also believe we must look for exoplanets (or moons of exoplanets) that are orbiting in the Goldilocks zones of their home stars where, in addition to allowing liquid water to be present, also is "not too warm nor too cold, but just right" to allow the chemistries that carbon-based life is based on.***

However, before beginning our discussion of how our scientists will conduct their searches for ET, the author must point out that many of our current life and space scientists (plus almost all of our astrobiologists) now believe that carbon-based life may not be the only "show in town" in the universe. The physical and chemical conditions may be quite different on many other planets and biological evolution in some of these strange places may have come up with

protective mechanisms to keep life going under the harshest of conditions, or even be based on alternative chemistries that find such conditions friendly rather than harsh. On earth, some exotic critters, i.e., our hyperthermophiles, can even live in boiling water! Much of the reason for the survival of the extremophiles on our planet has been evolution's ability to develop compensatory mechanisms that protects these organisms from harsh environmental conditions that would be fatal for the rest of us "wimpy" earthlings. Of course, evolution may have its limits – no scientists currently believe life can exist on the surface or interior of stars. However, the other extreme has engendered some support from a few scientists in recent years. Some astrobiologists now believe one of the extremely cold moons of the planet Saturn named Titan, which has a thick atmosphere that is made up of 90% nitrogen gases and 10% methane and other complex hydrocarbon gases plus a surface with liquid methane lakes, might possibly harbor some slow-metabolic almost-frozen forms of carbon-based or other alternative forms of exotic life-forms that have been able to adapt to such cold conditions. I will discuss this interesting possibility of life on Titan later in the present chapter.

In the remainder of this chapter I will begin the exciting task of bringing the reader up-to-date on mankind's search for ET. However, as stated above, because of economic necessity and scientific conservatism, this search will not be focused on finding possible exotic forms of life but on searching for carbon-based life analogous to that found on earth. Since we know absolutely nothing (nil!) about what "exotic" life might look or act like, or be made up of (chemically), our scientists would be totally clueless as to how to even begin such searches. Our best chance for succeeding, and for getting government monies to support additional studies, will be to look specifically for forms of life that we are familiar with. Since our type of carbon-based life was able to pop up once in the universe, it would seem reasonable to assume that it may have popped up more than once. This means we will need to focus on searching extraterrestrial bodies (planets or moons) where lots of life-sustaining liquid water is thought to exist, and where the different chemical by-products of carbon-based life processes can be easily detected with our current technologies. For example, specific chemicals or gases which, on earth, are detectable in either the atmosphere or on the surface and are known to be produced by or associated with our form of life will be the top targets on our search lists.[1] Some examples of such atmospheric gases are oxygen and ozone (which are associated with plant photosynthesis), carbon dioxide (especially when it occurs along with oxygen, could

[1]In 1990, NASA launched a special unmanned spacecraft (Galileo mission) to Jupiter that was designed to perform spectroscopic studies of Jupiter's atmosphere to determine what kinds of gases it contained. In order to get the spacecraft to Jupiter, the NASA scientists first had to make it circle the sun, then reapproach the earth where the earth's gravity would then act like a sling-shot to "toss" it in the direction of Jupiter. Carl Sagan talked NASA into having Galileo, prior to its being slung in the direction of Jupiter, to perform a spectroscopic study of earth to see if it could detect any special chemicals that might suggest earth harbored life. Galileo detected high levels of oxygen and methane in Earth's atmosphere plus signs of chlorophyll on the surface. All three of these chemical ingredients are known to be associated with carbon-based microbes as well as plants and animals.

be a metabolic waste product of animals), and methane gas (which on earth is commonly produced by certain types of bacteria as well as barnyard animals such as pigs or cows). Even more complex chemical substances on a planet's surface itself, such as the chlorophyll content of green plants, can be detected from space with light spectroscopy techniques. So, first things first - scientists at NASA and ESA have unanimously chosen to give top priority to "following the water" at least for the near future, in hopes of having the best chances of finding life out there.

SEARCHING FOR LIFE IN THE INNER SOLAR SYSTEM

The major advantage today's scientists have in searching for extraterrestrial life in our own solar system is that, thanks to computers and rocket science, we now have the means to look both from a distance as well as close-up for signs of present or past life. Many scientists now believe that this new technology may finally allow us to answer this age-old question before the halfway point of the new 21st century. Although it now seems almost certain that no advanced forms of intelligent or equivalent life-forms will be found in our solar system (except, possibly, as visitors or tourists from other solar systems), a rapidly growing number of scientists have begun to believe that more primitive life-forms, probably single-celled, but possibly multi-cellular, may now exist, or may have existed in the past, in several different locations in our solar system. We will begin our discussion of this exciting possibility by first reviewing the history and current status of the four inner planets, ***Mercury***, ***Venus***, ***Earth***, and ***Mars*** (**Figure 5-1**).

Mercury is the planet that is closest to the sun (distance of 36 million miles, and orbital period of 88 days). Because of its small size (diameter of 3,032 miles) and proximity to the sun, it (like Earth's moon) has not been able to retain any more than the barest trace of an atmosphere. Very little water probably exists on the surface of this extremely hot sun-baked

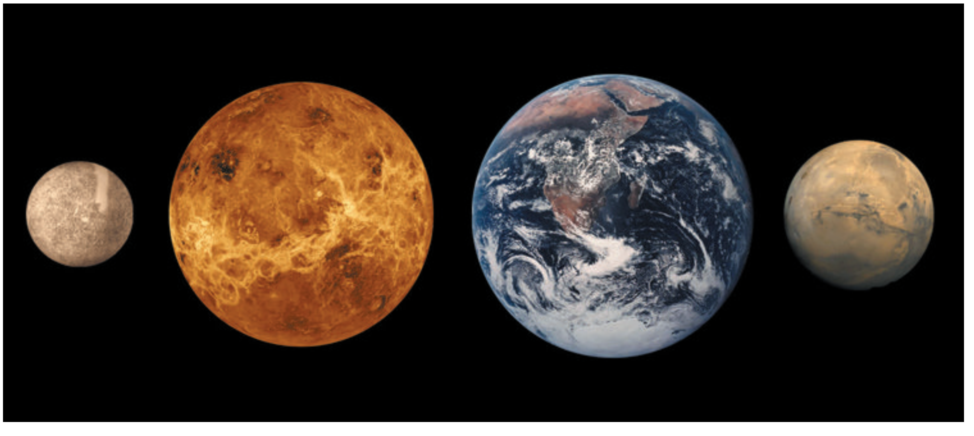


Figure 5-1 - Space photograph contrasts the relative sizes of the four inner planets. Shown from left to right are Mercury, Venus, Earth, and Mars. (Image credit: NASA)

planet. Some small traces of water-ice might be present at the bottoms of some of the deeper craters located at the north and south poles of the planet where it would be protected from being vaporized by shadows cast by the crater walls. (Similar pockets of water ice have now been found by NASA to exist on our own Moon which future lunar colonists can tap into.) Therefore, for purposes of the present book, we can bypass Mercury (and our own moon) as a possible location for life. However, the story for our next planet out from the sun, Venus, may be quite different.

Prior to the discovery that present-day Venus is far too hot and dry to support any known forms of life, science fiction writers and Hollywood movie makers had a heyday in imagining all kinds of exotic life on this planet, including thick jungles with dinosaur type creatures plus scantily dressed tribes of beautiful young women. While Venus is almost identical in size and mass to that of the earth (diameter close to 8,000 miles), it is located closer to the sun (67 million miles in contrast to earth's distance of 93 million miles). Venus today is incredibly hot with a mean surface temperature estimated to be somewhere between 850 and 900 degrees Fahrenheit (482^{o} Celsius). The atmosphere is very dense, with a barometric pressure at the surface that is 90 times greater than that of the earth. The entire planet is also totally encased in a very thick cloud cover that prevents seeing any surface features, at least in the visible portion of the light spectrum. However, many scientists now believe that Venus's situation at the beginning of the Archean Eon some 4.0 bya might have been quite different from what it is today. Venus at that time may have been almost literally a "twin" of the earth. If so, it might have supported the very early stages of development of carbon-based life-forms as did earth. While the surface of Venus today is far too hot to allow the presence of any liquid water at all, and its atmosphere is also extremely dry consisting mostly of 97% CO_2 plus about 3% nitrogen, the surface of early Venus might have been, at least for a short period, much cooler which would have allowed it to be covered by oceans and surrounded by an atmosphere containing large quantities of water vapor.[2] If this were the case, it is possible that heat-loving anaerobic microbes, similar to our own thermophiles might have started evolving.

However, the fact that Venus is located 26 million miles closer to the sun than is the Earth probably doomed the possibility of any further life-friendly development. Since the early Archean sun produced less heat than it does today, both Earth and possibly also Venus would, in the absence of any atmosphere, not have received enough solar heat to sustain liquid water on their surfaces. Many scientists believe that both planets did have atmospheres that probably contained sufficient quantities of CO_2 which could have provided greenhouse warming to keep

[2]During the Hadean Eon and heavy bombardment period, all four of the inner rocky planets (Mercury, Venus, Earth, and Mars) would likely have received frequent deliveries of water from objects (i.e., meteors, asteroids, comets) that frequently wandered into the inner solar system from the outer regions of the solar system where, due to the colder conditions, non-volatile materials (e.g., water, ammonia, methane) would have been able to accumulate in the accretion disc.

any early oceans liquid. For some unknown reason, however, it seems that the small amount of extra heat that Venus received from being closer to the sun prevented the rise of plate tectonics and the subsequent reduction in the magnitude of the greenhouse heating effect that later was able to occur on Earth. While the atmosphere of Venus is today still composed mostly of CO_2, Earth's total atmospheric CO_2 level today has dropped to a level of only 0.04%. The earth's early Archean atmosphere 4.0 bya, because of the presence of far more extensive volcanic activity, probably contained far higher CO_2 concentration levels than exist today. This would account for why the early Archean climate was typically hotter than today even though the sun was cooler.

However, as discussed in Chapter 4, thanks to plate tectonics, the vast majority of Earth's CO_2 is today safely tucked away as carbon-rich limestone and chalk deep below the ocean floors. This, unfortunately, is not the case for Venus today. The fact that plate tectonic processes were not available to remove the excess CO_2 gas from Venus' atmosphere possibly triggered what geologists call a ***runaway greenhouse*** effect. A runaway greenhouse effect occurs whenever the normal ambient temperature of a planet's atmosphere is so high (e.g, from being closer to the sun as in the case of Venus) that normal geological processes such as plate tectonics cannot remove CO_2 from the atmosphere fast enough to lower the air temperature. Instead of the climate being able to vacillate between getting cooler or warmer in response to periodic alterations in the amount of CO_2 in the atmosphere, the temperature just continues to rise, i.e., run away. In the case of Venus, the small amount of extra heat from the sun was just enough to swamp any inherent thermostat-like temperature control system the planet might have possessed. Whether this doomsday scenario for the failure of life to develop on Venus is accurate or not will probably never be known for sure. The surface of Venus is so hot today that no fossilized evidence of any kind of early life could possibly have survived to the present time. A few optimistic scientists today, however, believe there may be a very slight outside chance that examination of a sample of Venus' cooler upper atmospheric gases might reveal the presence of airborne microbes that managed to survive this early hell on Venus and evolve to take advantage of this higher altitude cooler environmental niche. Some scientists have even speculated that the solar winds during the earlier Archaen years might have picked up some of these high flying microbes and deposited them (still alive and kicking) into the earth's atmosphere. Thus, all life on earth may actually be descended from Venusians!

The next planet beyond Earth is the so-called "red planet" Mars. In contrast to Hollywood's brief foray into conjuring up possible exotic monsters and lovely ladies on Venus, Hollywood filmmakers and science fiction writers have had a more intense and even longer fascination with possible inhabitants of Mars. With Mars, it was not just the entertainment media that jumped on board the "Martians are a coming" bandwagon, but some serious scientists also got into the act. The reported findings by the American astronomer Percival Lowell in 1900 of what he thought were water irrigation canals on Mars gave the idea of an advanced intelligent race of Martians a huge amount of credibility which, of course, the entertainment and popular news media

pounced on. Today, scientists do not believe that any intelligent life-forms presently inhabit Mars, and no irrigation canals that might have been built long ago by a doomed race of Martian farmers have been found by any of our many NASA and ESA photographic spacecraft missions. However, the overwhelming evidence obtained by multiple fly by, orbital, and landing missions for the presence of substantial amounts of past and present water on this planet has triggered a growing resurgence among scientists of the idea that Mars, while not hosting higher life-forms, may be the home of more primitive forms of single- or multi-cellular life.

Figure 5-2 - Presents a side-by-side photographic comparison of Earth and Mars. (Image credit: JPL/NASA)

Mars is smaller than Earth (with one-half earth's diameter or 4000 miles) and located further from the sun (141 million miles in contrast to Earths distance of 93 million miles). **Figure 5-2** shows a side-by-side comparison of the two planets. While Earth and Mars are very different today, many scientists believe that, as may be the case with Earth and Venus, Earth and Mars may have been more similar at the beginning of the Archean Eon 4.0 bya. At that time Mars may have had a thicker atmosphere than it does today. While 4.0 bya, the sun produced 30% less heat for both Mars and Earth (as well as for all the other planets) than it does today, the early Martian atmosphere may have contained sufficient quantities of CO_2 or other heat retaining gases (e.g., water vapor and/or methane) that would have produced sufficient greenhouse heating of the planet's surface to allow the continuous or at least intermittent existence of liquid water. Although the amount of the Martian surface that was covered by water is still a hotly debated issue among scientists, the large number of photographic and exploratory robotic missions sent to Mars by NASA over the past 40+ years and, more recently, ESA has provided substantial evidence that early Mars may have had significant amounts of liquid water on its surface.

Figure 5-3 shows a collection of photographs taken during NASA and ESA orbital missions that show strong evidence that the ancient Martian surface may have hosted many different kinds of moving water sources such as tributaries, gullies, creeks, streams, and even large rivers. It also may have contained many larger standing bodies of water such as lakes, or small seas. Although Mars was probably never close to being a "water world" with large oceans as was Earth (and possibly, also early Venus), it did have sufficient sources of surface water to have produced evidence of occasional flooding and, according to a few experts, possibly small glacier-

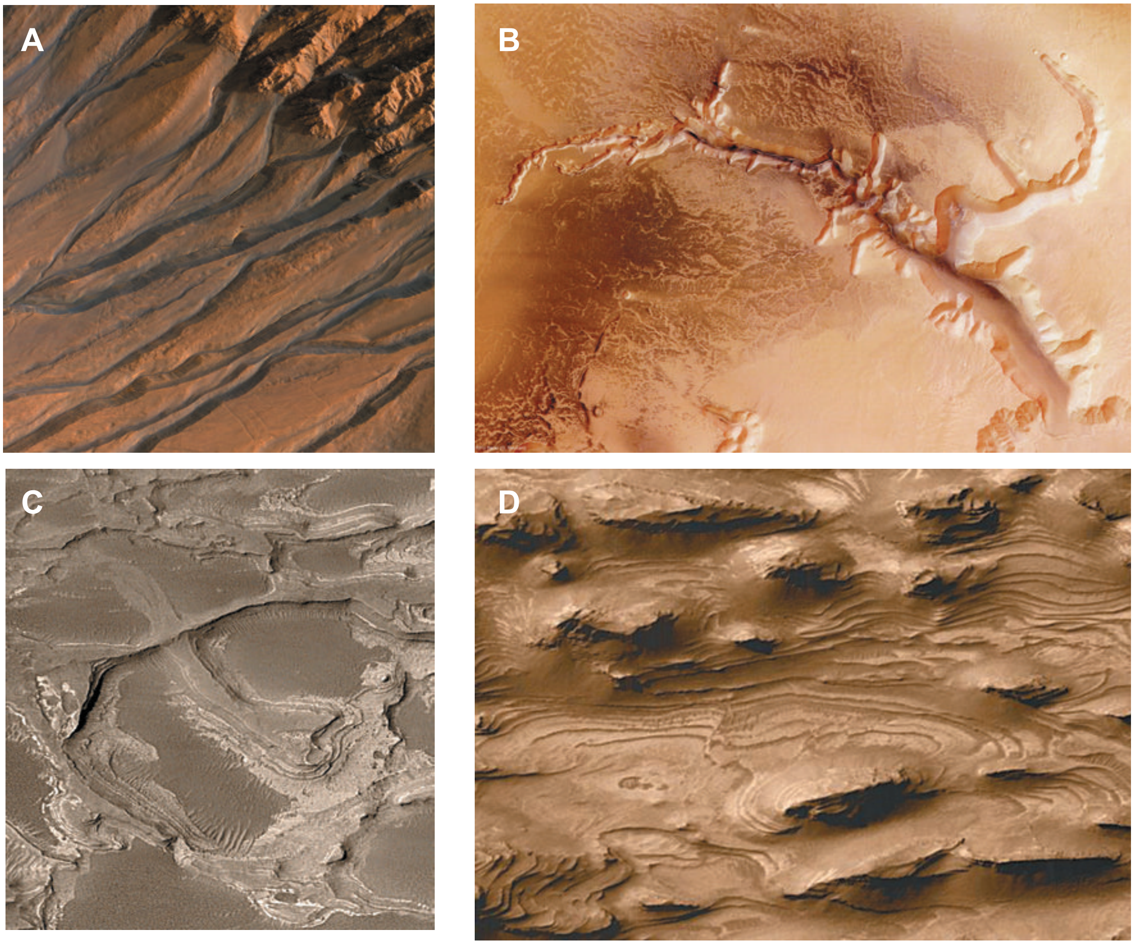


Figure 5-3 – Photographs taken from NASA and ESA orbital missions that show evidence of the existence of abundant surface water on Mars in the past. **A** shows evidence of ancient water channels (gullies) located on the walls of a crater. **B** shows an ancient dried up river bed with extensive inflow channels lining its banks. **C** shows evidence that some ancient rivers on Mars flowed for a long time, and not just in brief intense floods. **D** shows extensive patterns of layered sediment that may have been deposited over time by large bodies of water. (Image credits: NASA, JPL, ESA Mars Express, Malin Space Science Systems, Mars Global Surveyor, Goddard Space Flight Visualization Center, and University of Arizona)

like entities (**Figure 5-4**). At the end of the 20th century and continuing into the 21st century, a number of NASA orbital and landing missions found even more convincing evidence that Mars was at one time wet, and may, on occasion continue to be so today. The 1997 NASA ***Global Surveyor*** and the 2001 ***Mars Odyssey*** missions both obtained an enormous body of evidence that Mars once possessed significant bodies of surface water, and that some may occasionally escape from underground locations to the surface even today. During a three-week period in 2004, NASA's ***Mar's Exploration Program*** landed two small **Rovers** (i.e., small remote-controlled science laboratories on wheels) at two separate locations on the Martian surface using airbags to cushion their landings. One of these two Rovers (the NASA's ***Opportunity*** mission)

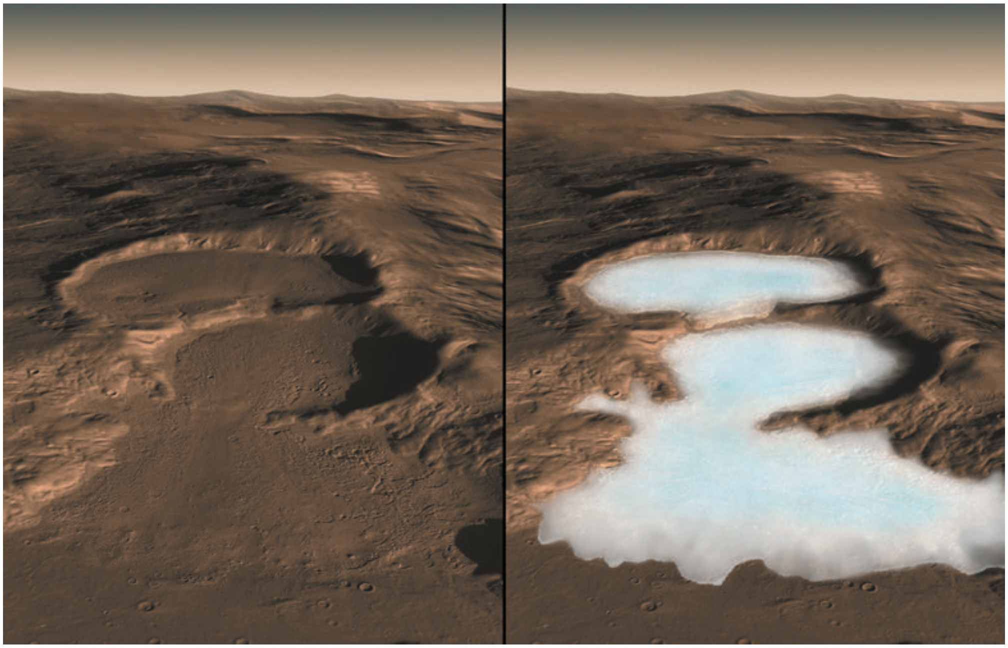


Figure 5-4 - A few scientists have even proposed that early Mars may have harbored small glaciers. The photograph on the left shows what might be geological structures or formations that could have harbored a glacier in the remote past. The picture on the right shows an artist's impression of what such a glacier might have looked like. (Image credit: NASA/JLP-Caltech)

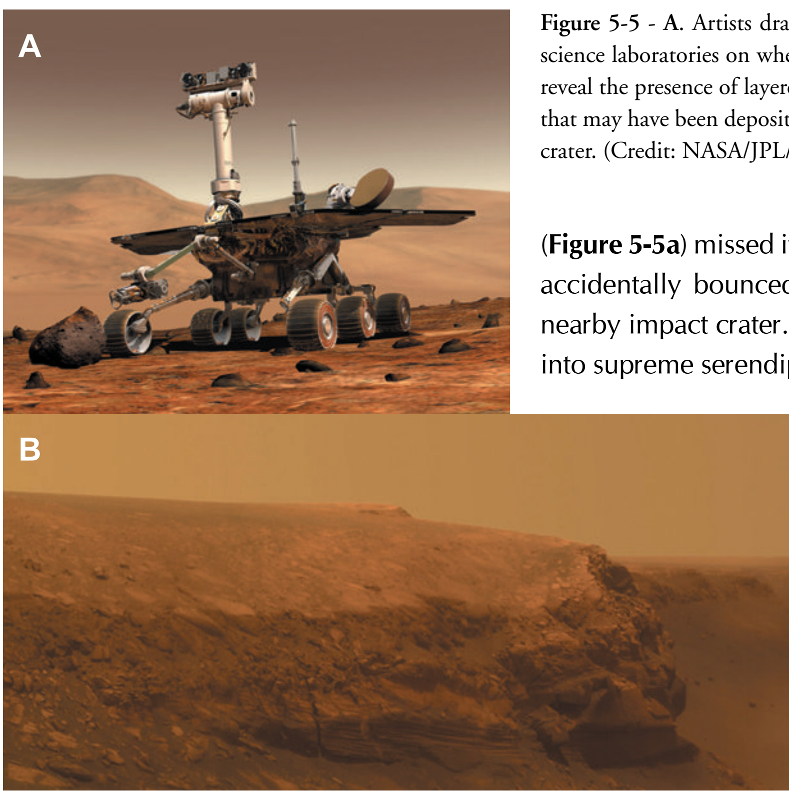


Figure 5-5 - **A**. Artists drawing of one of the two Rover mini-science laboratories on wheels that explored Mars. **B** appears to reveal the presence of layered sedimentary rocks on a crater wall that may have been deposited by a small lake that once filled the crater. (Credit: NASA/JPL/Caltech/Cornell)

(**Figure 5-5a**) missed its intended landing target and accidentally bounced into the bottom of a large nearby impact crater. This accident turned quickly into supreme serendipity. When the Jet Propulsion Laboratory scientists in Pasadena, California turned on the Rover's cameras they found it staring directly at crater walls that appeared to be made up of fine layered rocks (**Figure 5-5b**). Such layered geologic formations is what you

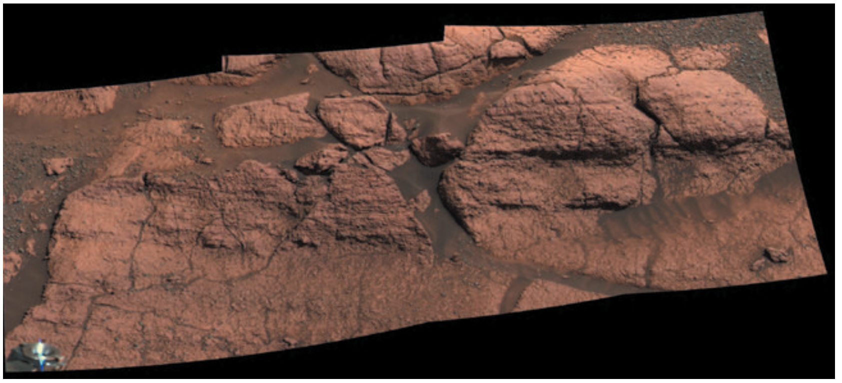


Figure 5-6 - Shows another photograph of a layered rocky outcrop on Mars that, if found on earth, would be most likely interpreted as the long term result of repeated depositing of sediments by large bodies of waters such as rivers, lakes, or small seas. (Photo credits: NASA/JPL/Cornell)

see on Earth along the banks of rivers where moving water has, over many eons, laid down layer upon layer of different sediment materials. Thus, Opportunity's little Rover had landed in what appeared to be a large crater that may have once been the floor of a small lake. **Figure 5-6** shows additional evidence of layered rocky outcrops from a second surface location on Mars. In addition to sediment deposits, the inquisitive little Rover spotted and photographed what appeared to be numerous small smooth round stone-like objects scattered around on the crater floor. These strange spherical objects, which are about the same size as small green peas, have been labeled by NASA scientists as "blueberries" (**Figure 5-7**) in spite of the fact that they typically appear more grey than blue in color. The NASA scientists measured the light spectrums of these blueberries (courtesy of a small spectroscope that the Rover had onboard) and found that they contained an iron-bearing mineral called *hematite*. On earth, such small rocks containing hematite can only be formed in extremely wet conditions. As further evidence of the early existence of surface water on Mars, the Opportunity Rover's "twin" (a second Rover labeled the ***Spirit*** mission which landed three weeks earlier on the other side of the planet) also drilled into some rocks and found they contained a special type of chemical called *sulfate salt* that can only be formed by the evaporation of liquid water.

Figure 5-7 – Shows a photograph of the so-called "blueberries" that were found lying on the bottom of a Martian crater by the Rover vehicle. On Earth, these types of small round stone-like objects are known to only be produced in extremely wet conditions. (Image credits: NASA/JPL)

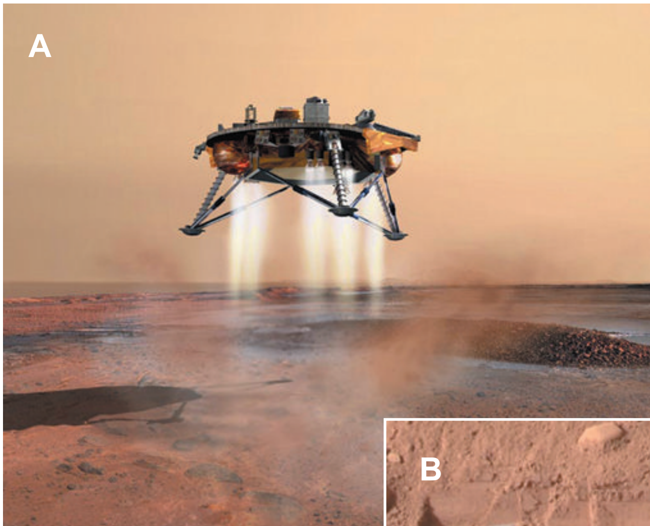
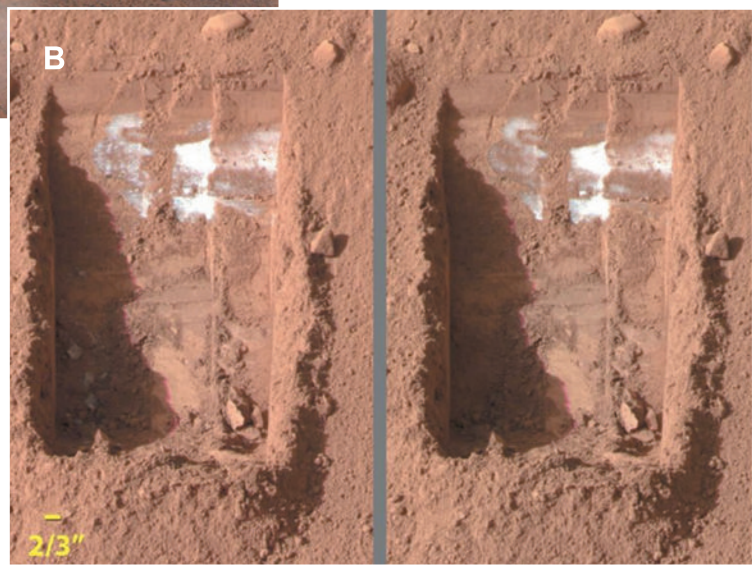


Figure 5-8 - Shows **A** an artist's drawing of the Phoenix lander that recently began searching for evidence of water at the Martian north pole. **B** shows small pockets of ice that the lander uncovered using a small shovel. The photographs were taken four days apart which reveals a small amount of evaporation of the ice. Some of the ice was later heated and the rising steam was confirmed to be water by spectroscopic examination. (Image credits: NASA/JPL-Caltech, University of Arizona)



Finally, as the present book is being written, NASA has started receiving reports back from its most recent robotic mission to Mars that had, as its primary objective, the search for water on or beneath the planet's surface. In late May of 2008, NASA's ***Phoenix Lander*** (**Figure 5-8a**) sat down near the north pole of Mars and began the task of using a small shovel to dig below the surface of Mars in search of evidence for either frozen or liquid water. THAT SEARCH NOW APPEARS TO HAVE BEEN SUCCESSFUL! The Phoenix NASA Lander has now confirmed that the subsurface at Mar's North Pole apparently contains extensive amounts of frozen water (**Figure 5-8b**). Finally, before closing this section of the book related to the search for water on Mars, I will offer one more piece of startling evidence for the existence of water on present-day Mars. **Figure 5-9** shows a photograph taken just recently (February, 2009) by the European Space Agency's (ESA) ***Mars Express*** spacecraft of what appears to be a pocket (or pond) of frozen ice at the bottom of a Martian crater. The crater is located close to the Martian north pole and is apparently deep enough that shadows cast by the crater wall protects the water from being evaporated by the sun.

Therefore, the evidence continues to "pour in" that Mars, at the beginning of the Archean Eon 4.0 bya had both water and a reasonably temperate (mild) climate that could have supported the beginning stages of primitive anaerobic life-forms. Some scientists believe the evidence for surface water on ancient Mars is now strong enough to justify showing artist's drawings of possible small oceans and river systems on early Mars (**Figure 5-10**). However, unlike the Earth which gradually increased

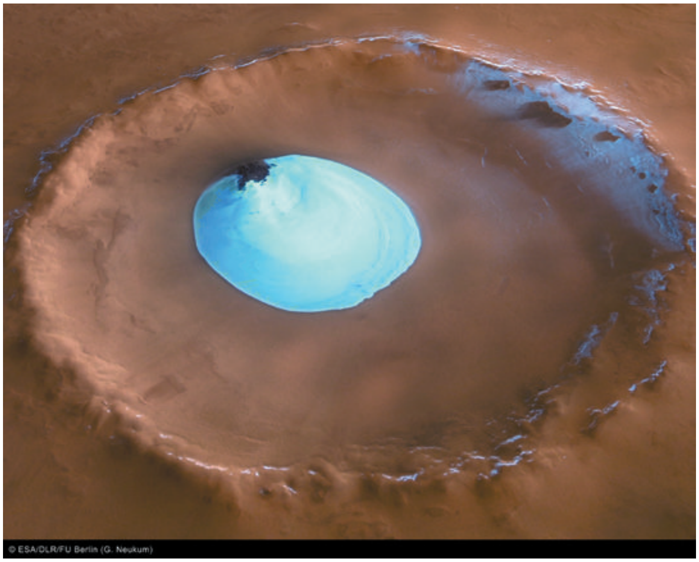


Figure 5-9 - Startling new evidence that surface water may today exist on Mars. This photo taken by the European Space Agency's Mars Express orbiter shows evidence of a pond containing frozen water at the bottom of a crater located close to the Martian north pole. (Image credit: ESA/G. Neukum)

its Life friendly assets (albeit for our familiar form of carbon-based life) over the next 4.0 billion years, Mars began to lose its resources. The smaller size of the planet and weaker gravitational field allowed the lighter gases to escape from the atmosphere at a faster pace than was the case for Earth. Also, since Mars probably does not have a large molten nickel/iron core like Earth, it may lack an electromagnetic field (i.e., that thing that makes a boy scout's compass needle point north) that is strong enough to help keep the solar wind[3] from stripping away atmospheric gases. Therefore, over time Mars gradually lost

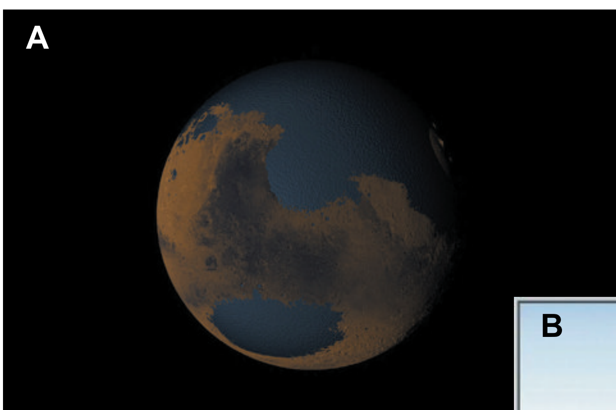
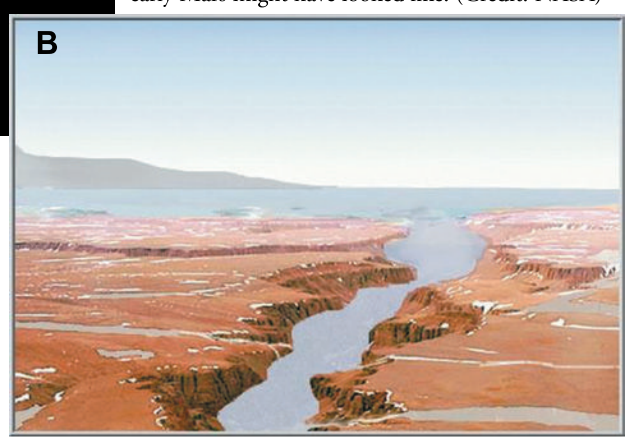


Figure 5-10 - The growing evidence for the presence of extensive bodies of surface water on ancient Mars has led to NASA artists putting forth images of what a wet early Mars might have looked like. **A** shows an artist's drawing of what Mars might have looked like circa 4 bya with oceans on its surface (Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio). **B** shows an artist's drawing of what the surface of a wet early Mars might have looked like. (Credit: NASA)



[3]All stars, during the main sequence phase of their lives, produce a "solar wind" that is made up of high energy radiation and sub-atomic particles that are continually blown outward from the surface of the star. This wind contains electrically charged particles that are diverted above and around (rather than through) the Earth's atmosphere by the magnetic field that is produced by the planet's molten core. Atmospheric gases in the Earth's upper atmosphere are therefore protected from being stripped away. On Earth a very aesthetic side effect of the solar wind is the occurrence of the bright and colorful northern lights (Aurora Borealis) and southern lights (Aurora Australis).

most of its atmosphere to the point that today's atmosphere is made up mostly of CO_2 (95%), nitrogen (3%) and only traces of oxygen, methane, and water vapor and its density today is approximately 1/100th that of Earth's atmosphere. (In contrast, the air pressure at the top of Mt. Everest on Earth today is 1/3 that at sea level; thus astronauts would need to wear pressure suits on Mars, plus bring along their own oxygen to breathe) While the atmospheric pressure of Mars might have been sufficient 4.0 bya to maintain liquid water on the surface, any exposed water, whether in the form of ice or liquid, would today be evaporated to gaseous water vapor (but perhaps not fast enough to always elude our scientist's inquisitive cameras, e.g., Figure 5-9). In spite of the fact that the sun continued to get warmer with time, the planet gradually became a very cold place with an average surface temperature today of -80 degrees Fahrenheit or -62 Celsius (which can range from as high as a balmy +70 degrees F at the equator to as low as -195 degrees F at the polar regions).

Therefore, It may be that at the beginning of the Archean Eon some 4.0 bya, our young solar system had *three blue worlds*, and not just one, that were covered by substantial amounts of surface water that were primed to support the beginnings of life. It appears that, early in the Archean Eon, Venus may have started down the road to becoming "too hot" plus "too dry" (the closer hotter sun would have been continually breaking water vapor molecules apart and removing moisture from the atmosphere) to become life friendly, Mars to being both "too cool and too dry" to easily do so, and Earth to being "just right" to easily make this transition. The primary factor that disrupted Venus' foray into the life friendly ranks was possibly a runaway greenhouse effect that might have been preventable if its orbit had been located just a little further out from the sun. Mars on the other hand, was the victim of a double edged sword. Its small size and possible lack of an electromagnetic field doomed it to rapidly lose its atmosphere, and its greater distance from the sun, plus only being one-tenth the size of Earth, allowed it to lose its internal heat sources more rapidly (smaller or no hot molten core, shorter and less intense volcanic period, less internal heat from radioactive decay).

The outside possibility that all three inner planets might have been able to develop early forms of primitive microbial life before beginning to go their separate evolutionary paths has led some scientists to suggest that life may not have originated on Earth but may have actually formed first on Mars. This idea of ***panspermia*** (which loosely translates as the ability of life to arise in one location in a solar system and be transported alive to other planets by meteors), while around but not taken seriously by most scientists for many years, has recently obtained some very intriguing scientific support. Some scientists now believe it is possible for primitive life (e.g., primitive microbial life-forms) to hitch a ride inside rocks or other debris blown away from one planet's surface (by an asteroid or comet impact) and survive the long trip and subsequent landing on another planet's surface. If this theory turns out to be true, and we do find life on Mars, that life may be our long lost cousins. We may all be Martians (or Venusians, whatever?).

It seems possible, then, that early in their histories, as Venus heated up, and Mars got colder, our Earth, thanks to plate tectonics found a way to develop a temperate climate by lowering the thermostat on our greenhouse heating system. On Earth, the climate became mild enough that life and the geophysical powers that be began co-evolving in earnest. While we have an excellent knowledge of what has happened on Earth, we know very little with respect to what may have happened on early Venus and Mars. The author needs to emphasize that, while many scientists support the possibility that conditions might have been favorable, at least temporarily, for life to get a jumpstart on all three of these inner planets, we do not yet know whether any form of life ever actually did manage to get started on either Venus or Mars. The idea that life could have gotten started on these two planets is strict speculation, but it is not without some factual support. I do know a few serious and very competent scientists who, while not gamblers, might be coaxed into placing a wager that life did get underway at least on Mars and may have been able to evolve fast enough to adjust to and survive in the slowly deteriorating Martian environment.

So, what is the story today with respect to the possibility of life on Mars? With the gradual demise of its atmosphere, greenhouse effect, and other sources of geothermal heat, Martian life, if it ever existed, may have been forced to go underground to survive. Life on the surface today would be continually bombarded by lethal doses of ionizing radiation from the sun as was the Earth prior to the development of the protective oxygen ozone layer in the atmosphere. In 1976, NASA tried to search for evidence of life on the surface of Mars. Two robotic landers (***Viking I*** and ***Viking II*** missions) carried out a series of biological experiments to see if they could find traces of carbon-based life similar to the microbes that live on Earth's surface (**Figure 5-11**). They scooped up small quantities of dirt from the surface and placed it into several sealed containers that then were subjected to different biological experiments. In one container, special instruments tried to test for the presence of organic molecules (i.e., molecules containing carbon) in the soil. No such organic molecules were found. This result was surprising since organic molecules are commonly found in other locations in space (interstellar gas and dust clouds, etc.) and the test

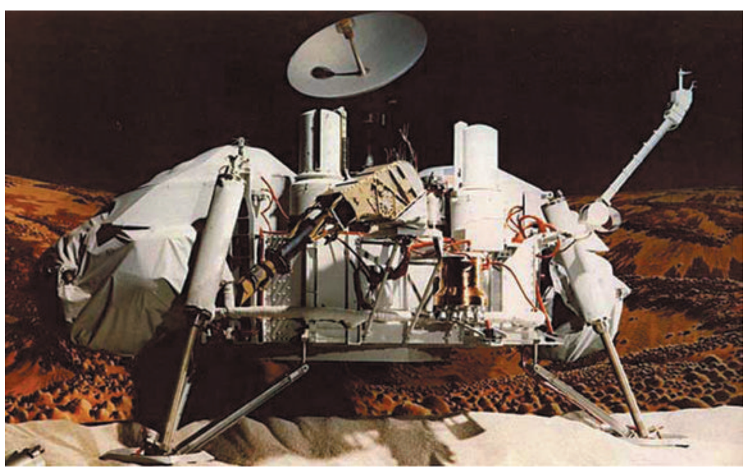


Figure 5-11 - In the late 1970s NASA sent two unmanned spacecraft to Mars to look for evidence of life on the planet's surface. Special instruments onboard the two Viking landers were designed to conduct special chemical tests to determine whether any living microbes might reveal themselves by ingesting a special "homemade soup" offered to them and then exhaling detectable waste products. (Image credit: NASA)

instrument itself seemed to be working just fine since it was able to detect small quantities of the solvents that had been used to clean the instruments prior to Viking's liftoff from earth. In another container, a soupy broth like substance (that contained small amounts of radio-labeled carbon) was mixed with the dirt and special instruments sniffed at the mixture to see if any microbes had eaten the broth and then begun to exhale carbon dioxide as a waste product. On the first try, definite evidence of exhaled CO_2 was actually found (small traces of radioactive CO_2 was detected), indicating that microbes might be present. However, on repeating this same experiment several more times, no further evidence of exhaled waste gas was found indicating the bugs were actually not there or got their fill of the soup and "decided" they really did not like it. The surprising finding of possible "exhaled gases" in this experiment, rather than being the by-product of life, is now believed by some scientists to have been the result of some kind of bizarre chemistry that was occurring on the surface of the planet as a result of the strong ionizing radiation from the sun continually interacting with some of the atomic elements (e.g. oxygen) that was contained in the Martian dirt. In yet another container, the scientists injected a sample of carbon-14 (a radioactive form of normal carbon) into a soil sample to see if any photosynthetic organisms might absorb the carbon (i.e., take it in and made it part of their own cellular structure), as such organisms on earth typically do. Evidence was initially found that there might be microbes present that actually did do this, but when they heated this container sufficiently to kill off any microbes that might be present they found evidence that something (or someone) was still soaking up the carbon-14. Since dead bugs should not be able to do this, the scientists concluded they had not found conclusive evidence of Martian microbial life.

However, NASA scientists David McKay and Rafael Navarro-Gonzalez recently (2008) performed some new research that indicates the failure of the 1976 Viking life detection experiments to find organic molecules in the Martian soil samples was the result of using incorrect test procedures. The new NASA Phoenix mission has now found that the Martian soil contains a type of chemical (a strong oxidizing agent named magnesium perchlorate) that would have affected the results of the Viking experiments. Because of the presence of this chemical (which can also be found in deserts on earth), any organic molecules that might have been present in the soil would have been destroyed by the Viking test procedures before they could be detected. This new evidence, while not providing any new proof of microbial life on Mars does reinforce the need to continue this important search. The lead scientist of the 1976 Viking project, Gilbert Levin, has argued for over 30 years that Viking did, in fact, find life. Before announcing the vindication of Dr. Levin, however, scientists will now need to take another look at samples of Martian dirt, either first-hand (via astronauts), or via samples returned by robotic space missions.

At the time, the failure of the 1976 NASA landing missions to find definitive evidence of carbon-based life (i.e., life as we know it on Earth) on Mars was a bit of an embarrassment for the NASA science team. It resulted in an almost 27 year hiatus in any further missions aimed at detecting life signs. It would not be until 2003 that the British would be brave enough to "give

it another try" by sending a robotic lander named ***Beagle 2*** to make another attempt at finding chemical evidence of Martian life. Unfortunately, this mission also ended in failure when all contact was lost with the spacecraft just a few days before it was scheduled to land on Mars. However, back at NASA's Lyndon Johnson Space Center in Houston, Texas, a small meteorite ("meteorite" is the name given to meteors after they fall to earth) had been sitting in a sealed collection box in a NASA warehouse since 1984 that would soon begin refocusing not only the space scientists but, more importantly, the world's attention back on the possibility that life might exist on Mars. In 1984 this small meteorite had been discovered in a snow drift in some remote ice field somewhere in Antarctica (**Figure 5-12a**). Teams of NASA scientists had, for many years, been making annual trips to this undisturbed and remote snow-covered part of the world to search for and collect anything (meteorites, or other objects) that may have fallen to Earth from the skies during the preceding year. Over many years, these pristine objects from space had been collected and distributed to laboratories all over the world for scientists to study. This particular meteorite had been sitting in a warehouse at the Johnson Space Center for almost 10 years when, in 1994, some scientist picked it up and gave it a closer look. Over the next two years a team of NASA scientists led by David McKay conducted tests that led them to conclude that this rock was indeed from Mars and that it also contained possible fossilized evidence of primitive Martian microbial life. This meteorite (which weighed slightly over four pounds) was discovered to have small air-filled pockets inside its rocky interior that contained gases that appeared to be identical to those thought to exist in the Martian atmosphere during the Archean Eon. While this rock may have originally formed on Mars as far back as 4.0 bya, special tests performed by the NASA scientists indicated it was not until sometime between 10 and 20

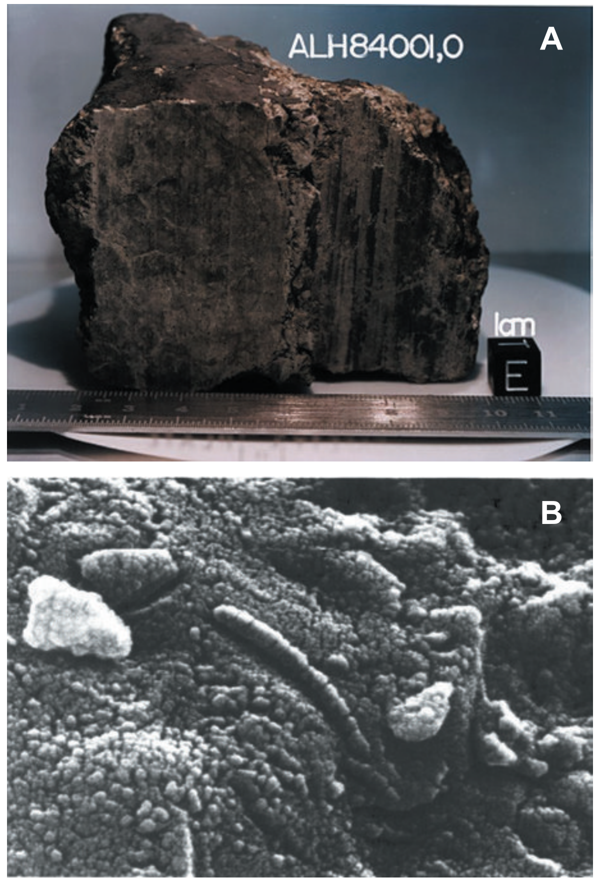


Figure 5-12 - Shows (**A**) the four pound meteorite which was ejected from ancient Mars by an asteroid (or comet) impact event. Careful examination of the rock revealed multiple pieces of evidence of what appeared to be chemical and fossilized evidence of primitive Martian life-forms. (Image credit: NASA/ESA) (**B**) shows a photomicrograph image of what many (but not all) of the examining scientists believe may be the fossilized remains of a Martian microbe that was found deep inside the meteorite. (Image credits: NASA/JPL-Caltech)

million years ago that it was apparently blasted off the Martian surface by an asteroid or comet impact. After wandering around in space for millions of years it finally crashed to earth about 13,000 years ago. In addition to containing bubbles containing Martian air, this small meteorite also contained something else that caused a world-wide news media frenzy that even included a news conference being held by William (Bill) Clinton, then President of the United States. Many newspapers around the world carried front page headlines announcing that "Life had been found on Mars".

The interior of the Martian meteorite was found to contain a number of individual pieces of evidence of what appeared to possibly be the fossilized remains of single-celled microbial life plus various chemical by-products suggesting that the rock had been exposed to liquid water in the past and may have housed past living organisms. **Figure 5-12b** shows a photograph taken with a microscope from inside this rock of what appears to be a fossilized Martian microbe. The reader might want to now quickly compare this photograph to those shown in earlier chapters of this book of currently living cyanobacteria (Figure 3-1b) and fossilized microbes (Figure 3-1a) found on earth. I will not go into the details of the evidence found by the scientists, but only state that while the entirety of the evidence made a strong case that Martian life might have been found, there were some doubts expressed by some of the examining scientists. These scientists believed that some of the individual pieces of evidence could have possibly been the product of non-living chemical or geological processes. Therefore, while the overall evidence for life was strong, the verdict of the "scientific jury" was not unanimous and beyond reasonable doubt. It now appears that we will need to find additional Martian meteorites that can confirm this evidence, or, better yet, launch special missions to collect samples directly from Mars and return them to our NASA and ESA laboratories for intense study.

Although many, but not all, scientists now believe that the geological and climatic conditions on early Mars might have been conducive to allowing the beginning stages of the evolution of single-celled prokaryote type organisms, it is likely that the Martian atmosphere lacked an oxygen ozone layer that could protect surface organisms from ionizing solar radiation. Therefore, the first Martian life-forms would probably have developed below water as likely did those on Earth. However, with the slow but steady loss of the atmosphere, and the resulting inability for water to remain in liquid form on the surface, the Martian microbes would have subsequently needed to relocate their homes to moist underground soils, to hot underground hydrothermal pockets near volcanoes (similar to the hyperthermophiles at Yellowstone National Park), or even to liquid aquifers (i.e., underground pockets of free-standing water, e.g., "water wells"). The fact that many different species of such tenacious critters have chosen to live in such locations on Earth would suggest that this might have occurred on Mars as well.

Most scientists today believe that, while life is absolutely rampant on Earth, and has been so for as long as possibly four billion years, the evidence for life on any of the other inner planets of our solar system is still, scientifically speaking, non-existent. However, the tremendous advances in the life, earth, and space sciences during the last half of the 20th century now

appears to have finally provided mankind the means to reevaluate this situation. While it is very unlikely that we will be able to obtain definitive evidence of whether life-forms might have ever arisen, even briefly, on Venus, we now have, in the case of Mars, the technology we need to answer this ancient question. If the U.S. Congress, or some friendly multi-billionaire, would provide the necessary funding, we could probably answer this very important question in just a few short years.

Possibility of Life in Outer Regions of Solar System

Until close to the end of the 20th century, most scientists believed that the possibility of viable life-forms anywhere beyond the orbit of Mars in our solar system was small to nil. The reason for this belief was simply that, in addition to being far too cold (even water is frozen solid), there were no known environmental conditions anywhere that could possibly allow carbon/water based life, as we know it, to exist. However, two important and unexpected discoveries have since totally changed this attitude among our scientists. The *first piece of evidence* has to do with the discovery of the so-called extremophiles among the ranks of our planets single-celled prokaryote life-forms. These bizarre life-forms appear to be capable of living in environmental niches that are so hostile that it would immediately kill any other form of life, including man, in an eye blink. It seems that the form of carbon-based life that has developed on earth includes many different species that can tolerate extreme environmental conditions that might allow them to survive in the extreme environments that are believed to possibly exist, if not on the planets, at least on a few of the moons of the outer solar system. And, of course, some of the more bizarre of these creatures only need geothermal heat and certain minerals to live and can survive quite well without oxygen or sunlight. The *second piece of evidence* is the discovery that liquid salt-water oceans may be present on at least one of the moons of the outer planets that could provide a comfortable home for some forms of "more traditional" (carbon-based) earth-like creatures.

The first such possible "water world" discovered in the outer solar system is one of the four large ***Galilean moons*** of Jupiter. While Jupiter is known to have a total of 63 moons, the Galilean moons are the only ones large enough to have been discovered by the Italian astronomer Galileo Galilei when he pointed his small homebuilt telescope at Jupiter on January 17, 1610. These moons, proceeding outwards from Jupiter, are known as ***Io***, ***Europa***, ***Ganymede***, and ***Callisto***. Europa is the smallest moon with a diameter of 2,000 miles, which is just slightly less than the 2,160 mile diameter of Earth's moon. Ganymede is the largest with a diameter of 3,400 miles. Early telescopic observations of the four moons revealed that Europa appeared to be the brightest in reflecting more sunlight than the other three. Of the moons, Europa appeared to most closely resemble a "snowball" in being whiter in color with fewer distinctive surface markings or features. **Figure 5-13** compares high resolution color photographs of these moons

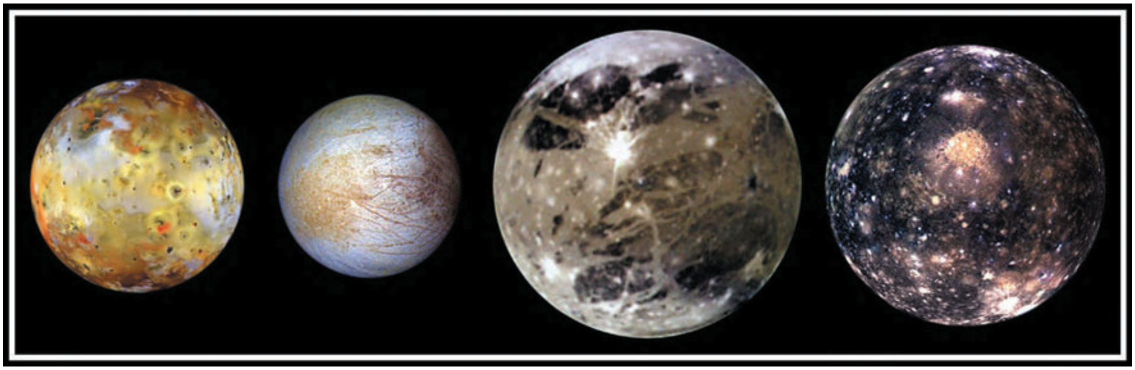


Figure 5-13 - Photographs of the four largest of Jupiter's moons. The moons from left to right are Io (the closest to Jupiter}, Europa, Ganymede, and finally Callisto. (Image credit: NASA/JPL-Caltech)

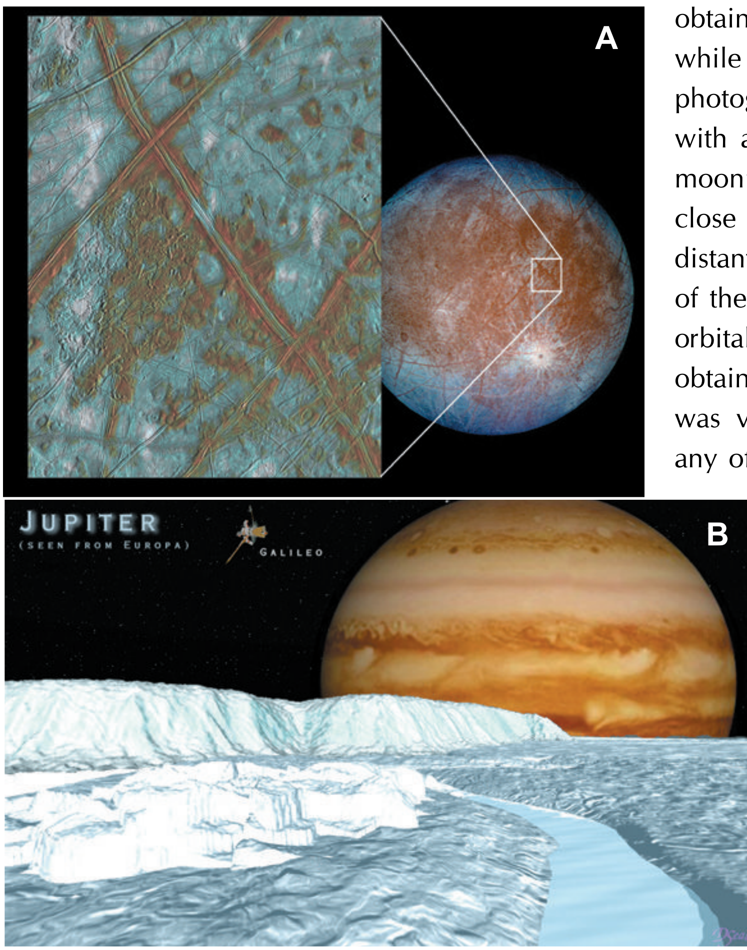


Figure 5-14 - **A** shows a photograph of Europa (right) along with a close-up view (left) of the moon's surface taken from a NASA flyby mission. **B** shows an artist's drawing of what the surface of Europa might look like. (Image credit: NASA/JPL/ University of Arizona))

obtained from NASA fly-by missions, while **Figure 5-14** shows a close up photograph of Europa's surface along with an artist's drawing of what this moon's surface might look like really close up with Jupiter rising above the distant horizon. Starting at the end of the 20th century, NASA fly-by and orbital science missions began to obtain mounting evidence that Europa was very unusual in comparison to any of the other moons or planets of our solar system.

The author will not go into a detailed historical description of these extremely interesting NASA investigations but will jump straight to the bottom line of what NASA scientists currently believe may be the status of this remarkable moon. Unlike our own moon which is a small virtually airless and lifeless ball of rock, Europa and some of the other moons of the outer

solar system are completely different and are currently forcing astrobiologists to totally rethink their ideas of what kinds of environmental criteria are needed to define a life friendly world. Europa may very well be a water world with saltwater oceans that are totally covered by a very thick layer of surface ice (**Figure 5-15a**). This ice layer may help to insulate it from the extreme cold conditions that are inherent by the Jupiter system's extreme distance (365 million miles) from the sun. And, now for the real surprise! Europa's oceans may be sitting on top of an internal heat source that is very different from the traditional internal planetary heat sources (molten core and radioactive decay) that we residents of the inner solar system are accustomed to.

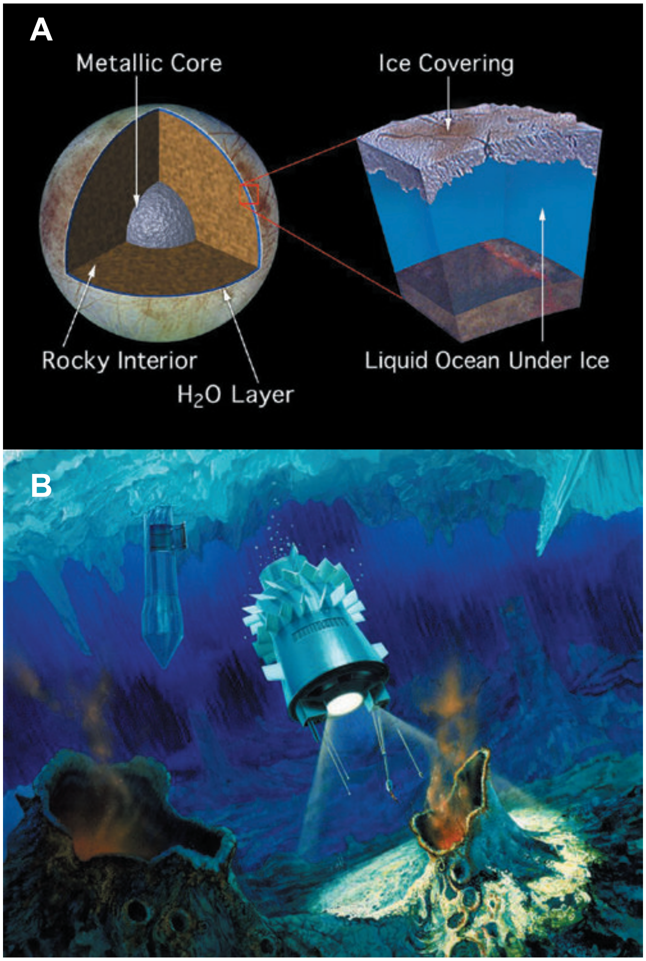


Figure 5-15 - A. Many scientists now believe that Europa may have a thick ice sheet (perhaps as great as 100 miles thick in some locations) which covers the entire surface of the moon. A saltwater ocean may be present below the ice sheet and this ocean may be warmed by heat from the interior of the moon. NASA is considering, hopefully in the not too distant future, sending unmanned missions to Europa that can drill holes through the ice sheet and insert special remote controlled miniature submarines (**B**) to search for evidence of life. (Image credits: NASA/JPL-Caltech)

The first three moons out from Jupiter (Io, Europa, and Ganymede) have a very interesting, but probably not unusual partnership in terms of how their individual orbital pathways around Jupiter are arranged, as well as how their orbits are related to each other. All three moons have slightly non-circular orbits around Jupiter, which means that as they orbit the planet some of the time they are slightly closer to Jupiter and at other times they are further away. Because of this constantly changing distance between each moon and Jupiter, the gravitational tug of Jupiter is continually changing in strength. This change in Jupiter's gravitational tug causes the innards of each moon (i.e., all of its internal matter) to be continuously flexed or stretched back-and-forth. This stretching or "bending" of each moon's interior creates heat, which is similar to the heat that is produced when a paper clip is rapidly bent back-and-forth until it breaks. The internal heat that is produced inside Io, Europa, and Ganymede by the constantly changing tugging action by Jupiter is called ***tidal***

heating. Under normal conditions, a moon that has an orbit around its home planet that is even only slightly non-circular would gradually change its orbit to one that is perfectly circular (as is the case with Earth's moon). When this happens, the moon would always be the same distance from its home planet and the tidal heating effect would eventually stop. However, with planets that have multiple moons, this changeover to a circular type of orbit may not always happen. Io, Europa, and Ganymede will not be able to eventually modify their orbits since each of the moons also exhibits a continually changing tugging effect on each other which prevents this from happening. The orbits of the three moons exhibit a type of physical *resonance* with each other in terms of how long it takes each moon to complete one orbit around Jupiter. For every orbit completed by Ganymede, Europa completes two orbits, and Io circles Jupiter four times. Astronomers now believe that, in solar systems with multiple orbiting planets, or with planets that have multiple orbiting moons, this tidal heating effect may be common. This means that even in the extremely cold outer regions of a planetary system it might be possible for carbon-based or other forms of life that require warmer temperate environments to pop up.

If Europa does have deep ice-covered oceans that are maintained in a reasonably temperate state by tidal heating, what kinds of life-forms could we expect to possibly have arisen? Whales or mermaids, NO! Some kind of primitive single-celled prokaryote microbes or slightly more complex single- or multi-cellular organisms, PERHAPS! We do know that, on Earth, it was possible many eons ago for primitive heat loving microbes to evolve at the bottoms of our oceans near hydrothermal vent systems where a continuous geothermal heat source was available to cook up a soup of hot water and various types of mineral substances. Whether something similar may have happened at the bottom of an Europian ocean is an idea that is now putting smiles on the faces of many of our NASA astrobiologists, plus "goose bumps" on the backs of their necks. The next obvious step in tackling this intriguing problem will be to launch special orbital and landing missions to look more carefully (using radar, spectroscopy, magnetic measurements, and other computer-age remote sensing tools) at Europa to see if we can find any clues as to what might be lurking in the waters beneath the surface. NASA flyby missions have seen evidence that, from time to time, cracks may occur in the surface ice that might allow ocean water and unlucky critters to get washed out onto the surface. A next step may be to land very sophisticated machines on the surface that can melt (or gnaw) their way through the ice to the oceans below and insert special robotic submarines that can snoop around, take pictures, and collect living specimens to return to the surface to be loaded onto spacecraft to be brought back to NASA for an absolute orgy of exciting science (**Figure 5-15b**). Unfortunately, such missions will be expensive and will probably not get funded real soon. However, this is not stopping some of our diehard scientists from trying to get a headstart on developing the scientific equipment that would be needed to do this. Scientists at the Jet Propulsion Laboratory (JPL) in Pasadena, California (and the California Institute of Technology) have started developing a special robotic machine called a ***Cryobot*** which, hopefully, will eventually be able to melt its way through such ice covers and deploy another special machine

called a ***Hydrobot*** to take pictures and possibly collect living specimens. The JPL and Caltech scientists have plans to build prototypes of these machines and actually test them in Antarctica. Antarctica has a large ice-covered lake named ***Lake Vostok*** that might have environmental conditions very similar to those that may exist on Europa. This lake has been totally isolated from the Earth's surface and atmosphere by a 2.5 mile thick ice cover for at least 500,000 years. The water in the lake is heated to some degree by geothermal sources beneath the earth and is thought to possibly contain some forms of ancient single-celled microbial life-forms.

While Ganymede also exhibits a tidal heating effect, its magnitude would be smaller than that found on Europa since this moon is located further from Jupiter. Scientists have recently suggested that Ganymede and, possibly also Callisto (which, unlike its three Jovian siblings, does not have an appreciable tidal heating effect), may also have saltwater oceans located below their hard crustal surfaces that could support some kind of primitive life-forms. In marked contrast, Io, being closer to Jupiter, has a much stronger tidal heating effect than the other Galilean moons. Io is not thought to house ice covered bodies of water since it is far too hot to allow this to occur. Io, being closer to Jupiter than the other Galilean moons is subjected to a much stronger gravitational tug-of-war with Jupiter and, as a result, suffers from a virtual run-away tidal heating effect. The internal tidal heating inside Io is so intense that the surface of this moon is thickly littered with very intense and active volcanic activity and the surface is mostly molten. This moon puts on quite a colorful and spectacular fireworks show for any passing NASA photographic missions (**Figure 5-16**). Far in the future, if mankind is still here and begins marketing tourist trips to the Jupiter system, Io will probably become one of the top selling attractions.

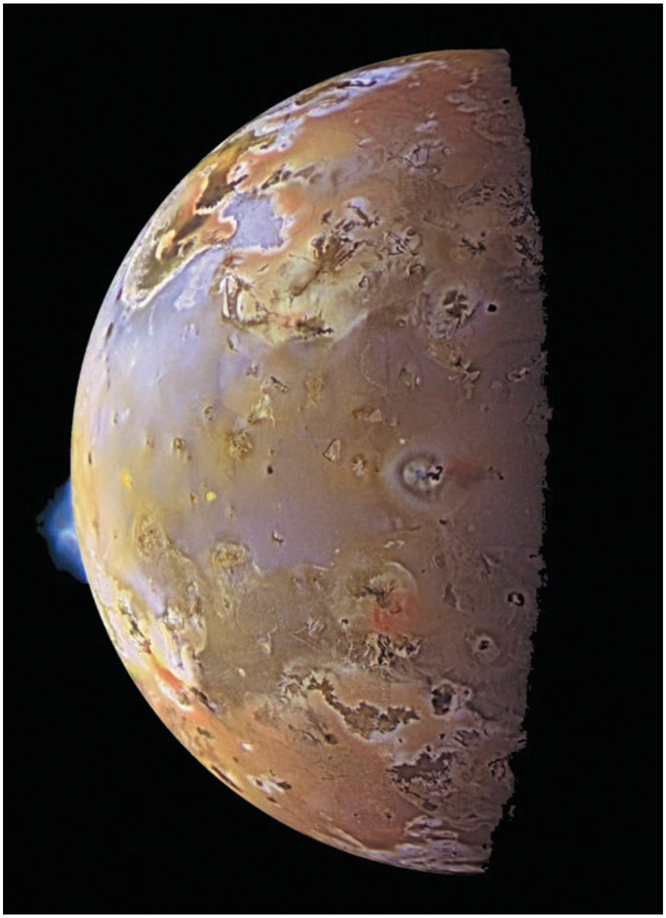


Figure 5-16 - Io is Jupiter's closest moon and continually engages in the strongest gravitational tug-of-war with its home planet. As a result, this moon is extremely hot, with a surface that consists mostly of hot molten magma and large numbers of violent volcanoes. One such erupting volcano can be seen on the lower left side of this NASA image of Io. (Image credit: NASA)

The next planet out from the sun, ***Saturn***, also has a moon that

has attracted a great deal of attention from astrobiologists in recent years because, it too, like Europa, is not a typical example of what astronomers traditionally believed moons should be. This moon, which is named ***Titan*** is quite different from the Earth's airless and mostly rocky moon, but it is also quite different from Europa. It has a diameter of 3,200 miles (Earth's moon is 2,160 miles in diameter), but it is unique in being the only moon in our solar system to have a thick gaseous atmosphere. In fact, Titan's atmospheric pressure at the surface (ground level) is 1.5 times greater than Earth's atmosphere. While Earth's atmosphere is made up mostly of oxygen (21%) and nitrogen (78%), with smaller amounts of argon (.1%) and carbon dioxide (.04%), Titan's atmosphere contains mostly nitrogen (85%) mixed with thick hazy layers of clouds made up of different types of hydrocarbon gases (mainly methane and ethane). Titan is located at a distance of 888 million miles from the sun and, as a result, is extremely cold with an average surface temperature of -288 degrees F. However, what has the astrobiologists so excited about Titan is that, even though it is extremely cold, its thick atmosphere is made up largely of the critical elements of carbon-based life "as we (once again) know it", i.e., hydrogen, carbon, and nitrogen.

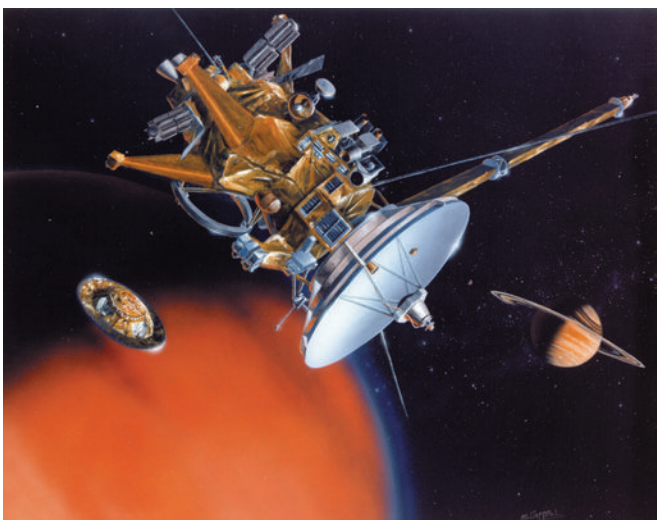


Figure 5-17 - Saturn's moon Titan is the only moon in the solar system to harbor a thick atmosphere. Both the atmosphere and surface of this moon contains a large variety of carbon-based chemical substances that might foster some form of alien life. NASA and ESA recently launched an unmanned landing craft to this moon to check out this possibility. This artist's drawing shows the Cassini spacecraft as it might have appeared just after releasing the Huygens lander (small disk like object to left of spacecraft).(Image credits: NASA/ESA/JPL)

Because of the possibility that Titan might be able to harbor some kinds of carbon-based life, NASA, in partnership with ESA, on October 15, 1997 launched an unmanned spacecraft named ***Cassini*** which arrived at the Saturn system (**Figure 5-17**) on Christmas day, 2004. This spacecraft contained a small landing craft named ***Huygens*** which was, on January 14, 2005, made to descend via parachute to the surface of Titan (**Figure 5-18a**). This probe took photographs and collected other types of data during its descent which confirmed evidence obtained several years earlier from earth-based and space telescopes which indicates that Titan, in addition to possibly having a life-friendly atmosphere might also harbor lakes or seas of liquid methane on its surface. The first photographs taken by Huygens as it descended toward the surface (**Figure 5-18b**) provided strong evidence in support of this possibility. Upon landing, the Huygens probe also confirmed that Titan's surface contains an abundance of rock solid frozen water in addition to numerous rivers, small seas, and lakes

containing liquid methane. **Figure 5-19a** shows an artist's drawing of what the surface of Titan may look like. Thus, the evolution of some form of life that has somehow managed to adapt itself to Titan's extremely cold climate is a possibility. However, based on what we believe we know about how carbon-based life is slowed up by cold conditions, any such Titan life-forms would likely have to age and evolve at an extremely slow pace. (Thus, the proverbial "fountain of youth" may turn out to be the methane seas of Titan!) However, the photograph shown in **Figure 5-19b** suggests another possibility. This specially computer-enhanced color radar photographic image taken from the Cassini orbiting spacecraft clearly shows that large portions of the Titan land surfaces are covered with many small lakes (not unlike what we see in the United States "land of 10,000 lakes", i.e., Minnesota) that might not all be filled exclusively with liquid methane. If any of the lakes are located over a subsurface hot springs system or near a volcano, they might be warm enough to allow the existence of liquid water. Such isolated "hot tub" lakes might foster a more temperate environment that could host truly bizarre or exotic forms of carbon-based life-forms (or maybe not so bizarre).

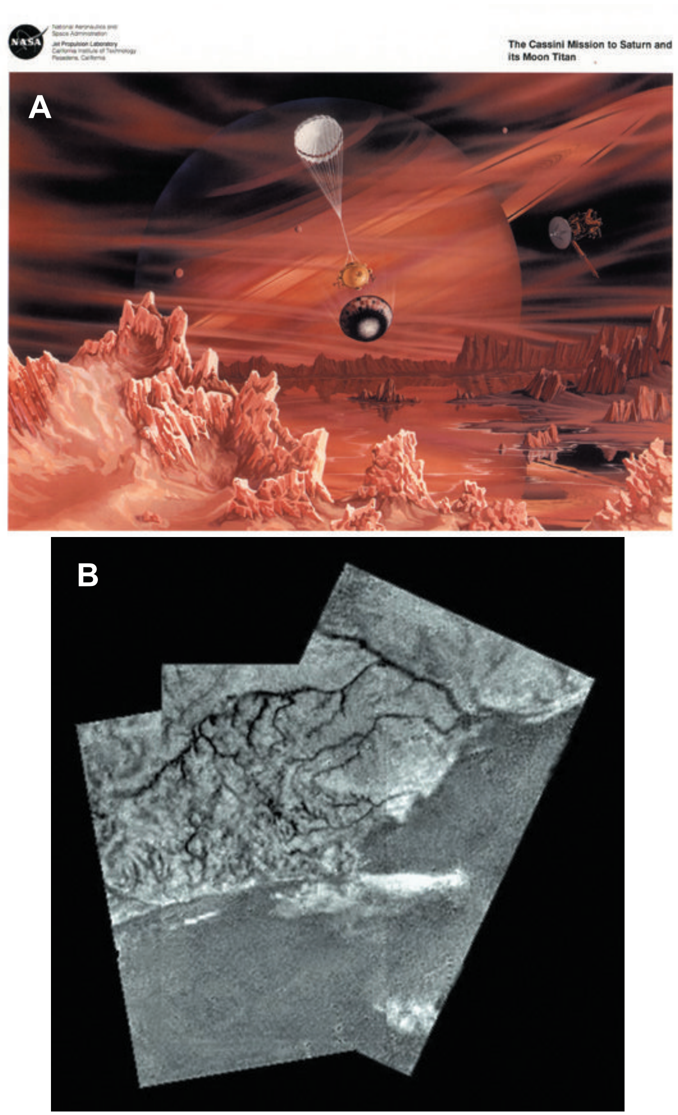


Figure 5-18 - **A** depicts an artist's drawing of the Huygens probe as it descends by parachute to the surface of Titan. **B** shows a visible light photograph taken from high altitude as the probe descends to the surface. This picture seems to show a landmass (upper part of photo) with tributaries flowing into an adjacent ocean or lake (lower part) probably filled with liquid methane. (Image credits: ESA/NASA/JPL/University of Arizona)

Before turning our attention to the search for possible extraterrestrial planetary abodes for life, we need to close out our discussion of the search for life in our solar system by briefly

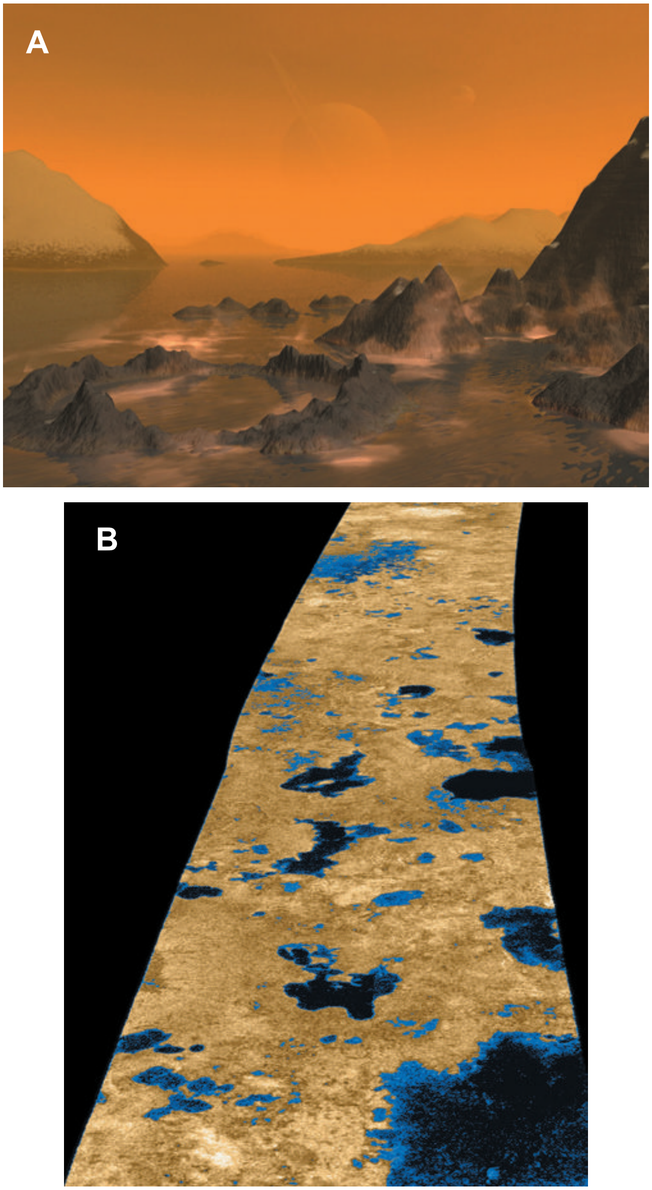


Figure 5-19 - **A.** An artist's view of what the surface of Titan might look like close-up (Image credit: Stan Richard/NASA/JPL). **B.** Shows a special kind of photographic radar image that reveals that many of the landmasses of Titan are covered by large numbers of small to large liquid methane filled lakes (Image credit: ESA/NASA).

describing what we think we know about the possible existence of life on the surfaces of the rest of the planets and moons of the outer solar system. Again, in terms of the search for carbon-based life, the biggest obstacle for such life is again the extreme cold conditions that get even worse as we head further out from the sun. While the elements needed for carbon-based life, i.e., hydrogen, carbon, and nitrogen, are more common in this region of the solar system (see Chapter 2 for why this is), the only liquid mediums that might possibly be available to support life would be methane or ammonia and even these chemicals start to freeze by the time you get as far out as Neptune or Pluto. Of course, except for Europa, water is totally frozen and unavailable as a life-sustaining liquid medium anywhere probably beyond Mars. Also, Jupiter and Saturn, and probably Uranus and Neptune do not have solid surfaces that would support land critters - the atmospheres of these planets in fact get thicker and thicker as you approach their central cores, until finally transitioning into a solid rock hard medium. Thus, carbon-based life even remotely similar to our familiar earthly forms is probably nonexistent in the outer solar system, although other more exotic forms of "life as we **DO NOT** know it" is possible. As discussed in Chapters 3 and 4, starting in the last half of the 20th century, science has begun to learn that life is much more flexible and tenacious than we previously thought possible. In the next section of this chapter, I will discuss new evidence that other planetary systems may not only be common in the universe, but may come in a large

number of different varieties that could open the door even further to the possibility of strange environments that could host even stranger forms of life that are quite different from those we earthlings are familiar with.

SEARCH FOR HABITABLE WORLDS BEYOND OUR SOLAR SYSTEM

The back-to-back discoveries at the end of the 20th century of *extremophiles* living on our planet plus *exoplanets* circling other stars is now motivating many of our astronomers to seriously consider changing their primary job descriptions to that of "planet hunters" or "astrobiologists". The fact that the new 21st century is witnessing a continuing surge of dramatic new discoveries in both of these important areas is also attracting record numbers of new students (and at least one retired college professor) to enter this exciting new field of science. By the spring of 2010, the planet hunters had identified a total of 490 exoplanets and our life scientists were continuing to discover many more varieties (species?) of extremophiles that are able to live in an even wider range of different hostile environments. These new unexpected findings have now opened the door to the distinct possibility that biological evolution may be a far more resilient and flexible biological process than earlier generations of life scientists could ever have imagined, and that life may actually be a relatively common phenomenon in our universe.

Although there were a few unconfirmed reports of discoveries of possible exoplanets prior to 1990, the real breakthrough came in 1995 when Michel Mayor and Didier Queloz of the University of Geneva announced the first definitive discovery of an exoplanet orbiting an ordinary main-sequence star (named 51 Pegasi). Unfortunately, in 1995 the technology that astronomers had available to detect exoplanets was not sensitive enough to detect any but the largest planets that were close enough to their stars to be orbiting at very fast rates. Therefore, while the late 1990s saw a sudden surge in exoplanet discoveries the technology of the time only allowed us to detect planets that were ***hot super-Jupiters***, i.e., planets many times larger than the gas giants (Jupiter and Saturn) in our outer solar system, and that were hot (with surface temperatures of several thousand degrees Fahrenheit) simply because they were orbiting extremely close to their home stars (with orbital periods measured in hours or days, rather than the 12 years required for Jupiter or even longer 29 years for Saturn). Between 1995 and 2002 a total of approximately 40 exoplanets were quickly discovered in succession but virtually all were super-Jupiter type worlds located very close to their home stars.

This preponderance of huge fast-moving giant planets among the first discovered exoplanets came as a complete surprise to astronomers since this configuration is markedly different from that of our own solar system. In our solar system the smaller rocky planets (Mercury, Venus, Earth, and Mars) are located much closer to the sun than are the gas giant planets (Jupiter, Saturn, Uranus, and Neptune). In our system, it is small hot Mercury (diameter of 3,032 miles and surface temperature as high as 750 degrees F) that races around our sun once every 88

days and not huge Jupiter (with a diameter of 88,846 miles) which completes its "yearly" orbit in a leisurely 12 years. Astronomers suddenly realized that our solar system might not be typical of how such systems are formed and we would need to reevaluate our current theories of solar system formation. However, while we will indeed begin reevaluating how typical our own solar system is, the early anomalous findings of the planet hunters now appears to possibly be due, at least in part, to the poorer sensitivity of the measurement techniques we were using at first.

The first method that astronomers started using in the early 1990s to search for exoplanets involved the detection of small "wobbles" in the movement of stars as they travel through space. If no exoplanets are orbiting a star, the path it takes through space will be a straight line with a constant speed. If the star has exoplanets orbiting it, the exoplanets will, as they circle the star, produce a small gravitational tugging effect on the star that will cause it to deviate from a steady straight-line path. Since wobbles are easier to detect when they are both big and fast, it is not surprising that the fast moving close-in super-Jupiters were much easier to detect than smaller exoplanets located in slower more distant orbits. Unfortunately, some wobbling stars are easier to detect than others. If the planet's orbital path is inclined at right angles to our line of sight (i.e., as if we were looking down from above or up from below the other planetary system), it is hard to see any evidence of wobbles through the telescope. If, however, our line of sight is directly opposite the plane of the orbiting exoplanet, the star's wobbles will be directly towards or away from us rather than up or down. To detect these exoplanets, the planet hunters did not need to rely on their eyes (or cameras). Thanks to the advent of computers, they could now use a much more sensitive detection procedure called the ***Radial Velocity method.*** This method has, so far, been the most productive means of detecting exoplanets. With this method, the planet hunters can detect the star's wobbles by measuring the *Doppler Effect*. **Figure 5-20** (see also Figure 2-19 and the author's explanation of the Doppler effect presented in Chapter 2) illustrates how the Doppler effect can be used to detect stellar wobbles produced by orbiting exoplanets. Basically, as the star moves in the direction of an observer on earth, the light waves get closer together and the star will appear slightly bluer in color. When the star moves away from us, the light waves become further apart and the star appears slightly redder.

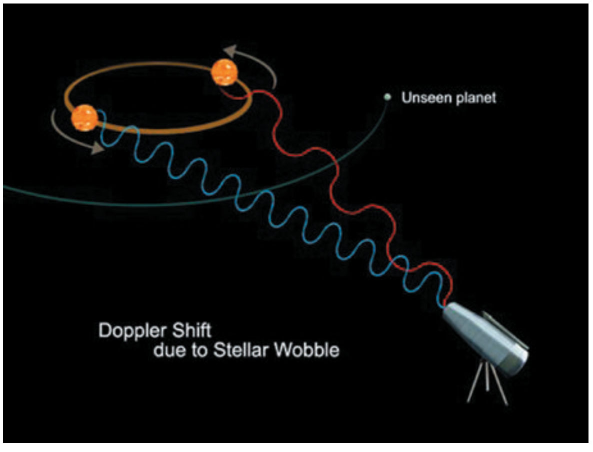


Figure 5-20 – Depicts the ***radial velocity*** method that the planet hunters use for detecting exoplanets, This technique relies on the fact that exoplanets orbiting their parent star will gravitationally pull on the star and alter its motion through space. When the direction of the star's wobble is either in the direction of the earth, or away from the earth, the wobble can be revealed with the ***Doppler Effect.*** (Image credit: NASA/JPL-Caltech).

Very quickly after the turn of the 21st century, astronomers began to refine and

improve the sensitivity of the radial velocity method. This increased sensitivity was accomplished mainly by a combination of building newer and more sensitive earth-based telescopes, plus launching space telescopes that could eliminate the interference effects of the atmosphere. Also, sensitivity was greatly augmented by the simple technique of gathering more data, i.e., making more frequent and longer duration measurements over longer periods of time. As a result of these technical improvements, while super-Jupiter type exoplanets continued to still be discovered, with some still close to their home stars, other super-Jupiters with longer term orbits also began to be discovered and, most importantly, astronomers also started finding exoplanets that are smaller and located further from their home stars. However, per NASA's decision to limit initial searches to forms of carbon-based life similar to that found on our planet, the Holy Grail of exoplanet searching is still to find earth-size rocky planets in orbits far enough away (i.e., in continuously habitable zones) from their home stars that liquid water can be maintained on their surfaces. At the time of the writing of this book (spring of 2010), as the sensitivity of the radial velocity technique continues to improve, and after discovering a total of 490+ exoplanets (which has accelerated to a rate that is now a little over two per month), no such earth-like worlds have so far been confirmed. However, we are getting closer and closer. In the past few years we have begun to find relatively fewer and fewer super-Jupiters and more and more so-called "super-earths" that are considerably smaller than the super-Jupiters with masses as small as 3 or 4 times that of the earth.

The rapidly increasing sensitivity of the radial velocity method has also allowed the planet hunters to obtain two additional very important pieces of evidence from their exoplanet searches. First is the finding of the existence of stellar systems containing more than one exoplanet. As of January, 2010 a total of 45 such multiple planetary systems had been identified. One such exoplanetary system, which is located approximately 40 light years away, has five separate planets, ranging in size from a super-earth that is about three times the mass of earth to a super-Jupiter object about four times larger than our own Jupiter. The star that these five planets are orbiting is about the same mass as our own sun. The increased sensitivity of the radial velocity technique has now started allowing astronomers to examine in greater detail the exact manner in which the wobbles of the home stars are modified by the presence of multiple exoplanets as opposed to just a single planet. In multiple systems, the wobble of the home star is changed from a simple repeating curve (or *sine wave*, for those readers who stayed awake in their high school or college mathematics classes) to a repeatable but more complex form of wobble. The astronomers can take the complicated wobbles (or the equivalent changes in the Doppler Effect over time) of these stars and mathematically determine what kinds of simpler individual sine waves the complex wobble is composed of. These individual sine waves can then tell the astronomer how large each exoplanet is plus how far away it is from the home star.

It has also just recently (as of 2004) become possible for astronomers to actually take photographs of alien planetary systems. In Chapter 2, I described a technique that astronomers use to view and photograph the gas and dust clouds (i.e., accretion discs) that surround newly

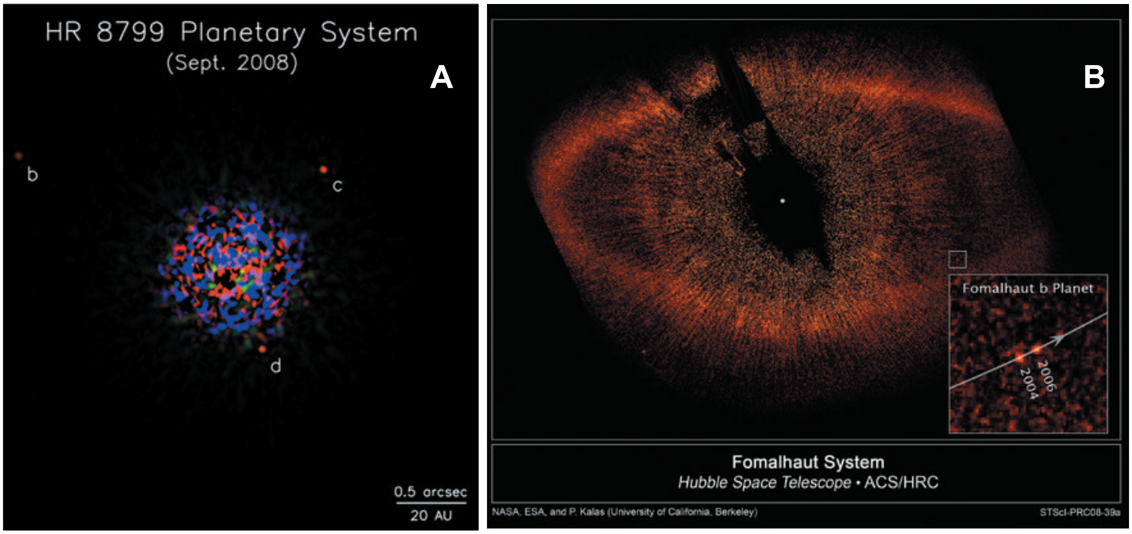


Figure 5-21 - Thus far, the only exoplanets that have been directly photographed by astronomers are a few very large ones, i.e., so-called ***super-Jupiters***. **A** shows three super Jupiter type planets orbiting a sun-like star that is located 130 light years from the Earth. (Image credit: Keck and Gemini Observatories/C. Marcis et al., NRC Canada). **B** shows a large dust ring (i.e., accretion disc viewed from above rather than edge-on) that was photographed by the Hubble telescope. The sun-like star (named Formalhaut, which is 25 light years from earth) would normally be seen in the center of the dust ring but has been purposively blocked out to allow astronomers to see the surrounding dust ring and any exoplanets that might have already formed. One such super-Jupiter planet has been recently photographed (lower right box) as it advanced in its orbit between the years 2004 and 2006. (Image credit: NASA/ESA/P. Kalas, Univ. California, Berkeley)

forming stars (proto-stars). In newer telescopes, it is possible to use a special computer-based optical attachment (called a *coronagraph*) to selectively block out the light from the extremely bright proto-star so that the surrounding gas and dust cloud can be easily seen, studied, and photographed. Figure 2-22 shows how this procedure is performed. With this technique, the planet hunters can now detect and photograph nearby exoplanets without interference from the light of their home star. **Figures 5-21** and **5-22** present several examples of recent photographs of exoplanets circling other stars. Of course, all of the exoplanets seen in these photographs are super-Jupiters. This method of blocking the light from stars in order to directly view nearby exoplanets unfortunately does not yet allow astronomers to photograph smaller earth-like planets. However, NASA does have plans, in the next few years, to develop and launch special coronagraph telescopes into orbit that would be able to do this. By eliminating the interference of earth's atmosphere, such space telescopes (see left side of Figure 2-7b) would be able to block the light of the home stars and allow us to detect earth-size or even smaller exoplanets. As we will shortly see in this chapter, the technology needed for this and other even more sensitive forms of exoplanet searches is now well within mankind's reach if we could find the monies to pay for the needed implementation of the new technology. The author needs, however, to point out another major restriction on our present ability to search for other exoplanetary systems which will not likely be overcome any time soon. Our universe is so incredibly large

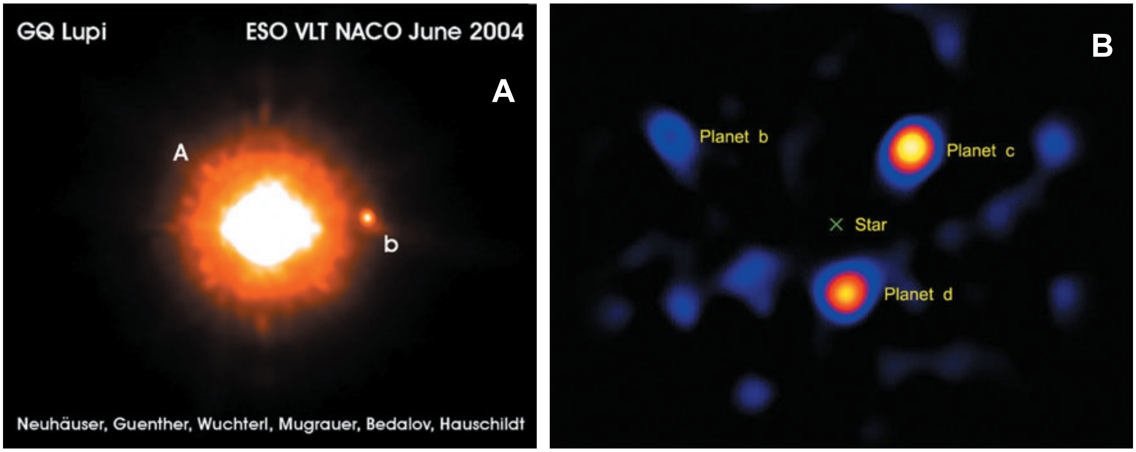


Figure 5-22 - Shows two more recent photographs of exoplanets circling sun-like stars. **A** shows GQ Lupi which is 250 light years away (Image credit: European Southern Observatory). **B** shows an exoplanetory system recently (2008) discovered by the Caltech Hale telescope that is 120 light years distant from earth (Image credit: NASA/JPL-Caltech/Palomar Observatory). All of the orbiting exoplanets of both stars are believed to be super-Jupiters although the GQ Lupi planet might possibly be a brown dwarf (i.e. a star that is so small it cannot sustain thermonuclear reactions in its core).

that we can only search for such worlds in our own small corner of the universe (or in our own "backyard", so to speak). **Figure 5-23** shows how extremely small our search area really is.

While advances in the use of the radial velocity detection method has, since 1995, allowed astronomers to discover that other planetary systems similar to our own may be relatively common in the universe, these procedures only allow us to determine the physical characteristics of exoplanets (e.g., mass, diameter, orbital period, distance from home star). What astrobiologists really want to do is look at the planets, collect samples of the light they reflect, and perform detailed spectroscopy type studies to determine the chemical composition of the planet's atmosphere and surface.

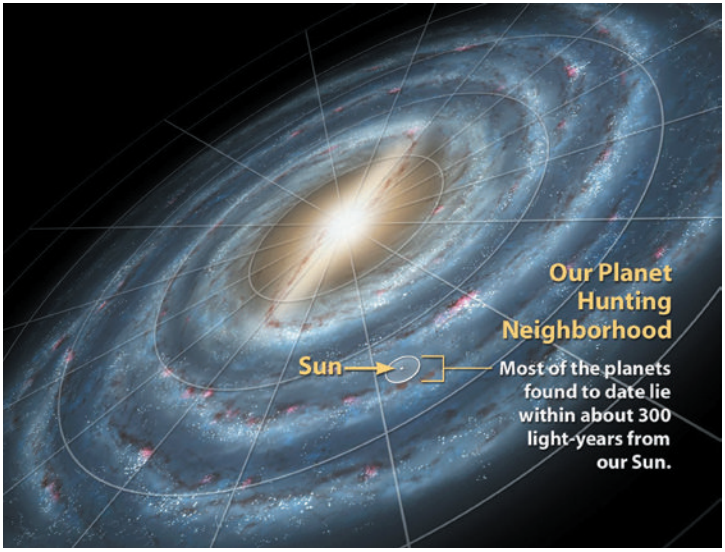


Figure 5-23 - It is important for the reader to know that, at the time of the writing of this book (2010) the technology that the Planet Hunters have available for detecting exoplanets usually does not allow the detection of exoplanets that are further away than about 300 light years from the earth. This NASA artist's drawing shows how incredibly small this search area is in comparison to the size of not only our own galaxy, but the rest of the vast universe as well. (Image credit: NASA)

Physical measurements will only allow us to determine whether the planet probably has an appropriate range of physical characteristics (size, mass, distance from star, temperature) that might allow it to support carbon-based forms of life similar to those found on our planet. An understanding of the types and amounts of different gases that are contained in an exoplanet's atmosphere can provide us important (but still indirect) evidence of the presence or absence of life.

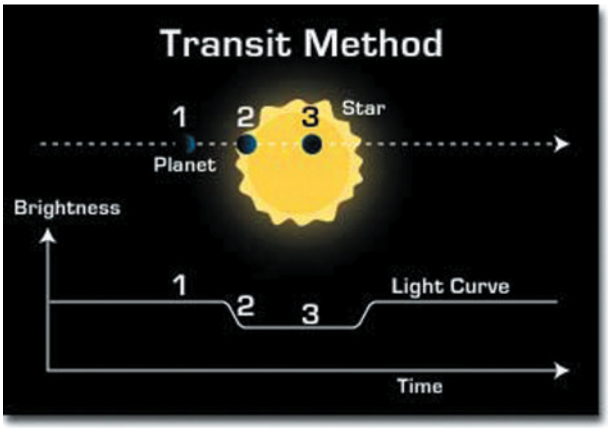


Figure 5-24- The second most productive technique for detecting exoplanets is the *transit* method, shown in this artist's drawing. When an exoplanet crosses in front of its home star, it will block a small amount of the light from the star. This brightness reduction may be detectable. The Kepler space telescope, launched by NASA in March 2009 will be able to detect such brightness changes produced by exoplanets as small as the Earth or even smaller as they pass in front of their home stars. (Image credit: NASA)

Fortunately, the planet hunters are also now using a second technique for detecting exoplanets that may be able to provide this important chemical evidence, and that is the ***Transit method***. This is what we see during solar eclipses when the moon moves in front of the sun and temporarily blocks out its sunlight. If the orbit of a distant exoplanet lies in the same plane as our line of sight, it would periodically move across the face of its home star and partially block out the star's sunlight. **Figure 5-24** depicts what happens during such transit events. With the transit method astronomers can measure a number of important pieces of evidence including the amount by which the exoplanet reduces the star's light (clue to how big the planet is), plus how long it takes the planet to complete the transit (a clue to the distance of the planet from its star). A related technique called the ***Secondary Transit method*** has been recently investigated by some scientists as a possible means for gathering some tentative clues as to what the chemical composition of the exoplanet's atmosphere may be. This method (**Figure 5-25**) relies on the fact that the exoplanet and the star sometimes "overlap their images" (when the exoplanet is in front of its home star) and, at other times, the exoplanet is behind its home star and not visible. Astronomers can take the "blended" light from the overlapping star and planet and use special computers to subtract this light from that of the star when the planet is behind the star. The resulting "difference" light can then be subjected to spectrographic analysis to determine what kinds of unique chemicals might be present in the planet's atmosphere that are not present in the star's atmosphere. Some recent investigations that used this technique have tentatively identified the presence of some important life-related chemicals such as water vapor, carbon dioxide, and methane in the atmospheres of some recently discovered super-earths.

In addition to the radial velocity and transit methods, the planet hunters have a third method that is being used to detect the presence of exoplanets. This technique relies

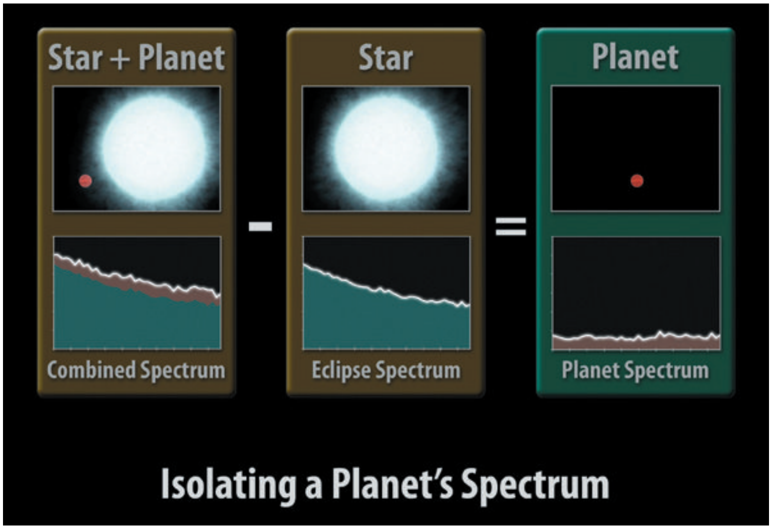


Figure 5-25 – Illustrates how a new variation of the transit method, labeled the ***secondary transist method***, can be used by scientists to determine the chemical makeup of an exoplanet's atmosphere. (Image credit: NASA/JPL-Caltech Spitzer Telescope)

on a phenomenon labeled ***gravitational microlensing*** that has a direct link to Albert Einstein's Theory of Relativity. In proposing that space and time is actually curved rather than flat in shape, Einstein predicted that light waves, rather than traveling straight through space, would have their paths bent by gravitational forces whenever they passed close to a star. This gravitational produced bending of light has now been confirmed by scientific studies. **Figure 5-26** illustrates how this detection method works. If a closer star passes directly in front of a more distant star, the gravitational field of the closer star will actually bend the light from the distant star and cause it to be more

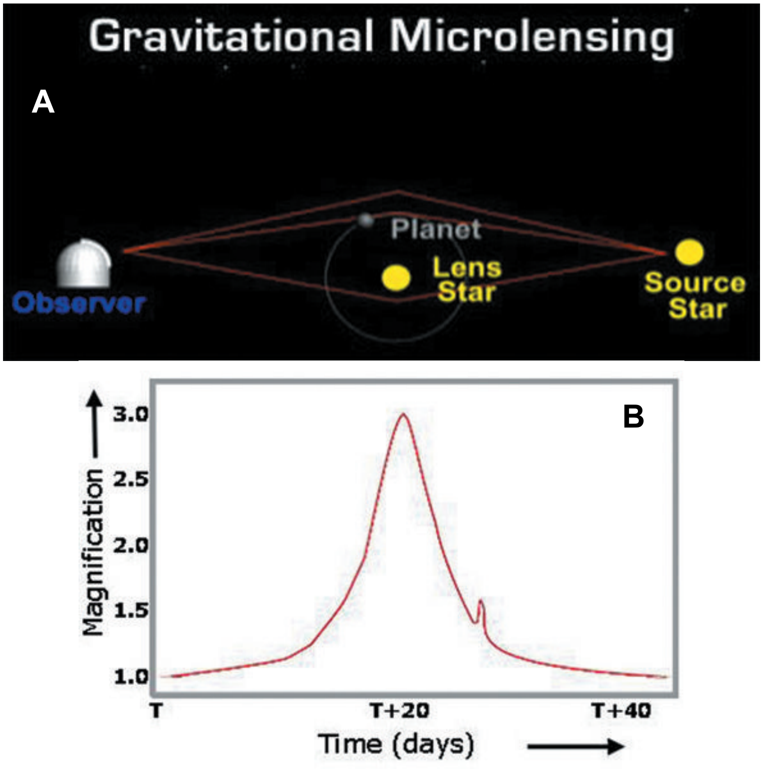


Figure 5-26- A. Depicts the third and, so far, least effective technique for detecting exoplanets, the ***gravitational microlensing*** method. A description of this more complicated technique is presented in the text. (Image credit: NASA). **B.** Shows a typical microlensing light curve that occurs when a closer star and its exoplanet companion passes directly in front of a more distant star. The small peak on the right side of the larger curve is produced by the gravitational field of the exoplanet itself. (Image credit: ESA Rosetta Programme)

focused on any earth-bound observers. As the closer star moves in front of the more distant star the brightness level of the distant star will appear to increase and will reach a maximum brightness when directly behind the closer star. If the closer star has an exoplanet circling it, the planet's own gravitational field will produce a secondary bending and focusing of the distant star's light thereby producing a second small spike in the apparent brightness of the distant star. While the ***Gravitational Microlensing method*** thus far has been considerably less productive than the other two techniques for detecting exoplanets, it has the potential of being developed as an automated process that would be less expensive and demanding of the planet hunter's valuable time.

It appears, therefore, that as the technologies underlying all of the exoplanet detection methods continue to improve, astrobiologists may very well begin to find that other life-friendly planets are relatively common in the universe. Of course it may well turn out that while planetary systems are common (several experts have recently estimated that between 20 and 50 percent of all sun-like stars may host planetary systems), all planetary systems may not be cut from the same mold. Some planetary systems (e.g., those that foster close-in super-Jupiters) may not be life-friendly, except for those exotic non-carbon-based life-forms that NASA has not yet given scientists the "green light" to look for. The presence of close-in gas giant planets would likely interfere with the formation of small earth-sized rocky planets like earth.

Mankind has the Technology to Detect Earth-like Worlds Orbiting other Stars plus Search for Evidence of Living Inhabitants

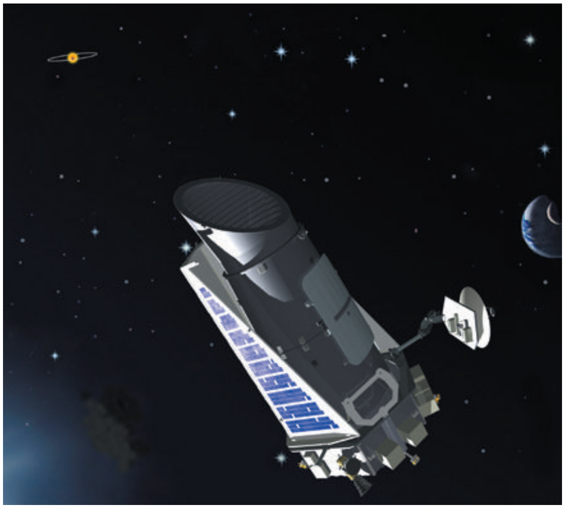


Figure 5-27 - Shows an artist's drawing of the ***NASA Kepler space telescope*** that will be able to use the transit method to detect the presence of smaller earth-like worlds circling other nearby stars in our Milky Way galaxy. (Image credit: NASA/JPL).

As discussed above, the technologies for detecting exoplanets has been steadily improving since the detection of the first exoplanet in 1995. On March 6, 2009, NASA launched the first space telescope that will be totally dedicated to searching for extraterrestrial planetary systems. This ***Kepler mission*** (named after a famous German mathematician and astronomer from the 17th century) will, for 3.5 years, or possibly longer, monitor 145,000 relatively near-by stars for signs of exoplanetary transit events. ***The Kepler Planet Finder System (Figure 5-27) will be able to detect rocky planets as small as the earth (or possibly even smaller) which are located in the continuously***

habitable zones of their home stars where liquid water may be available to support life. The Kepler space telescope is using a new type of extremely sensitive *photometer* (a special light meter that can detect very small changes in the brightness of objects) to simultaneously monitor groups of stars to determine if any of them exhibit small changes in brightness. Such small changes in brightness would indicate that an exoplanet is passing (transiting) in front of the star and blocking some of its light. If the Kepler mission is successful in finding substantial numbers of earth-sized planets in such life friendly orbits around their home stars, the next step will be to build and launch even more sensitive instruments for ***directly viewing and investigating the chemical composition of the exoplanets' atmospheres and physical surface features***.

The biggest hurdle that these new direct visual observation techniques will need to overcome is the fact that such exoplanets are located relatively close to their extremely luminous (visually bright) home stars, and the further away the exoplanetary system is, the smaller the apparent separation between the star and its orbiting planet becomes. All planets, exoplanets definitely included, do not emit light but only reflect an extremely small amount of the light that their home star generates. Stars typically outshine their planetary companions by an absolutely incredible amount. Our sun generates 1,000,000,000 (one billion) times more total light energy (all wavelengths combined) than is reflected by planet Earth, but only 1,000,000 (one million) times more if just the infrared portion of the light spectrum is measured. Therefore, the problem that astronomers face in trying to directly view a distant exoplanet is comparable to trying to view the light reflected by a flying insect (housefly or bee) that is circling around at a distance of a few feet from a powerful search light located several miles away.

One solution to this problem would be to place telescopes containing extremely large optical systems (e.g., mirrors for collecting light from distant stellar systems) into orbits above the Earth or to build them on the surface of the moon. However, the problem is that optical systems (mirrors) big enough to allow us to see distant planets in sufficient detail to determine whether life is present, would be ENORMOUS! Telescopes of the necessary size to accomplish this task are, for the foreseeable future, totally impossible. ***However, the advent of powerful high speed digital computers during the second half of the 20th century has allowed our scientists to come up with an absolutely amazing solution to this problem.*** What astronomers can now do is to use several spatially separated telescopes (either land-based systems such as the Keck Observatory "twin" telescopes in Hawaii or the newly constructed even larger European Southern Obervatory's "*Very Large Telescope*" (*VLT*) in southern Chile which has four large telescopes linked together) to simultaneously gather light from distant celestial objects and then send the images to a special computer that can digitally "add and subtract" the different individual components (i.e., light waves) from the distant objects' light spectrums to produce a composite image that has much higher optical resolution and clarity than is possible with each individual telescope alone. This new

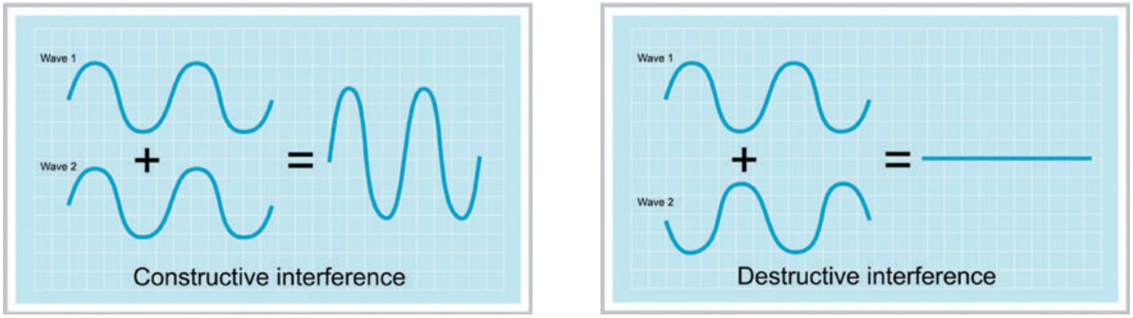


Figure 5-28 – Depicts the two types of interference that occurs when light waves encounter each other in space. (Credit: www.astro-canada.ca, ASTROLab du parc national du Mont-Meganic)

computer assisted multiple telescope technique is referred to by scientists as ***interferometry***. In order to eliminate atmospheric effects and obtain much better images than is possible even with the best land-based interferometry systems, our astronomers are now planning to place flying formations of several smaller spatially separated telescopes into high earth orbits. The separate smaller space telescopes, like their land-based cohorts, will be electronically connected so that the light collected by each of them will be fed into a special computer which then digitally processes the individual images.

Now, how do the computers themselves work their magic to produce this amazing trick? Since the early 1800s scientists have known that light propagates (i.e., moves through space) as waves, like waves on the surface of water. When two light waves meet, they interact with each other. Scientists refer to this interaction as "interference" **(Figure 5-28)**. If the crests (or troughs) of two waves are coincident (perfectly aligned), they will combine (add) together to produce an amplified wave in what is called constructive interference. However, if the crests of one wave are completely aligned with the troughs of the other wave, they will totally cancel each other out and the light will disappear. This effect is called destructive interference. Between these two extremes (which scientists refer to as being "totally in- phase" or "180 degrees out-of-phase"), the two waves may be only partially "phase-locked" (aligned) which will permit large variations in the brightness or dimness level of the combined light. Basically, interferometry permits astronomers to ***take advantage of the physical phenomena of constructive and destructive interference to digitally separate the extremely dim light being reflected by an exoplanet from the horrendously bright light being emitted by its home star***. Since the home star and the exoplanet are located in slightly different locations in space, and the individual telescopes of the ***flying formation*** are also located in different locations, the pathways the different light waves take in traveling from the exoplanet/star pair to the different telescopes will exhibit extremely small differences in both length as well as travel time. Today's computers are able to take advantage of the constructive and destructive interference that results from this situation to mimic the optical resolution capabilities of single

gigantic telescopes, as depicted in **Figure 5-29**.[4] For several years, NASA scientists and engineers have been busily working on developing ***flying formations*** of such individual smaller telescopes that could be placed in high earth orbit to assist in detecting exoplanets. **Figure 5-30** shows an artist's drawing of what the first ***Terrestrial Planet Finder*** or ***TPF*** system might look like. While the system has been completely designed and tested and is ready for construction, the U.S. Congress has not yet approved the necessary funds for this task.

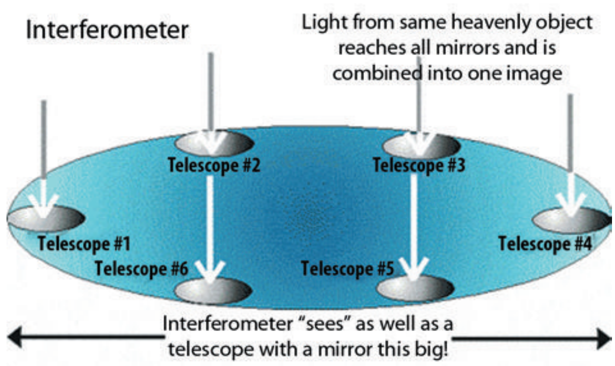


Figure 5-29 – Shows how the scientific principle of **interferometry** works. (Image credit: NASA/.JPL)

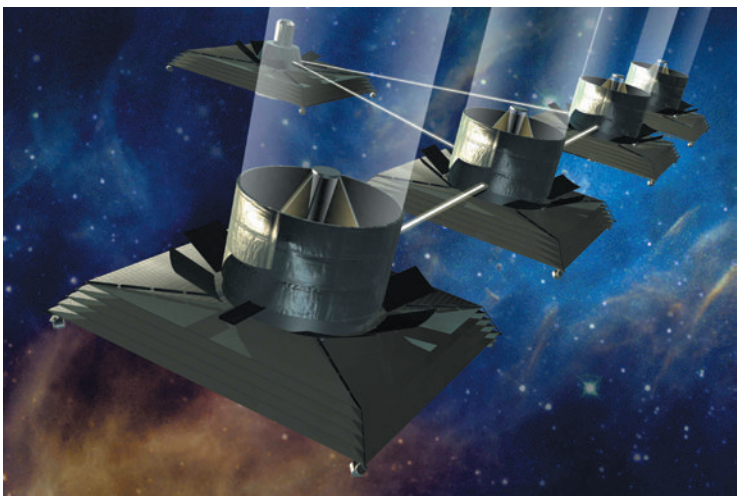


Figure 5-30 - Rather than placing single large telescopes into space (which would be very difficult, and very expensive), NASA has developed a much cheaper and potentially more powerful (in terms of what can be seen) alternative solution. Future space telescopes will consist of ***flying formations*** of large numbers of smaller telescopes that will all be electronically linked together by computers to simulate a single gigantic telescope. Shown is an artist's drawing of what the first NASA ***Terrestrial Planet Finder*** will look like. (Image credit: NASA/JPL)

What kinds of Evidence for Life will Astrobiologists Search For?

For obvious economic and technical reasons, the first generation of the TPFs will not have interferometry systems that are large and sophisticated enough to get the kinds of detailed visual

[4]The author needs to emphasize that the rise of digital computers at the end of the last century not only opened the door for scientists/engineers to develop interferometer telescopes, it also allowed similar breakthroughs in the biomedical fields. As a clinical audiologist, I used a method called "digital signal averaging" to separate the electrical activity of small populations of nerve cells located deep in patients' brains from the ongoing and much more intense and extensive activity occurring in other surrounding regions of the brain. This "neural evoked potential" procedure also utilizes the physical phenomenon of constructive and destructive interference to separate extremely small wanted signals from huge unwanted signals, except now it is electrical activity from brain cells instead of light from celestial objects.

views of exoplanets that astronomers would like. As Galileo's small handheld telescope was a mere toy in contrast to today's gigantic telescopes (e.g., the Keck "twin" 400 inch interferometry telescopes in Hawaii, and the former 200 inch world record holder Mt. Palomar telescope in California, see Figures 2-5 and 2-6), future versions of TPF systems will get larger and larger plus more sensitive, although not good enough to read headlines from newspapers on distant exoplanets, even on a clear day (topless alien sunbathers of the female persuasion can relax).

What the TPF systems will be looking for are any signs of the presence of chemicals in the atmospheres or on the surfaces of exoplanets that are ***out of equilibrium*** (i.e., different) from what would be expected to be present based on known physical and chemical laws of nature as well as the specific type and location (size, composition, distance from parent star, etc.) of the exoplanet. If an alien civilization in the Alpha Centauri star system (which is a little over 4 light years away from us) had a TPF system in orbit around its home planet, it would probably be able to detect the presence of water vapor, carbon dioxide, methane, nitrogen, and free oxygen in the Earth's atmosphere. All of these gases in combination, would be a strong clue (but not definitive) to the presence of extensive carbon-based life-forms on our planet. As we saw in earlier chapters of this book, the presence of free oxygen gas in the atmosphere of a world that does not harbor life would be unexpected since oxygen is notorious for bonding with other elements and making itself invisible to spectrometry. The reason we have so much free oxygen in our atmosphere is simply because we have extensive plant life that is constantly replacing it. For the first two-thirds or more of the history of Earth, our Alpha Centauri astrobiology colleagues would not have been able to detect our oxygen. It was only following the arrival of cyanobacteria and other forms of plant life which proceeded to rapidly build and inject huge quantities of oxygen into our atmosphere that oxygen would have been detectable. Carbon dioxide, while not itself a strong indicator of carbon-based life could, in combination with oxygen suggest the presence of animal life (if not volcanoes or forest fires) that ejected this gas as a metabolic waste product. Large detectable quantities of methane in a planet's atmosphere is also suggestive of life (e.g., especially the larger smelly varieties such as cows, pigs, etc.). Like oxygen, methane cannot survive "out of equilibrium" in an atmosphere without some means of continuously replacing it, most typically via life processes. Small quantities of methane can be, however, sometimes formed via volcanic activity. The recent detection of small quantities of methane on Mars has stirred a debate among scientists as to whether some of the Martian volcanoes might still be active enough to do this, or whether colonies of subsurface methane-producing bacteria (e.g., anaerobic *methanogens)* might be churning it out as a metabolic waste by-product.

Which Stars are Likely to Host Life-Friendly Worlds?

At least for the foreseeable future, astrobiologists will give top priority to searching for extraterrestrial life-forms that are "most like us earthlings". Since our form of carbon-based life

requires plenty of available liquid water, reasonably stable and temperate climatic conditions, plus a long "incubation" period to allow life adequate time to evolve and become established, scientists will be first looking at stars that are similar to our own sun. Since our planet required a time period of close to four billion years to allow the slow transition from primitive microbes to so-called intelligent human life-forms, we will look first at smaller stars that burn their hydrogen fuel more slowly and spend a longer period of time on the stable main sequence portion of their lifespan. As we learned in Chapter 2, stars come in a very wide range of sizes, from small less massive dwarfs to the very large and very massive giant and super-giant varieties. Less massive stars do not need to burn their hydrogen fuel as quickly as do larger more massive stars in order to maintain a stable level of thermonuclear reactions in their hot cores. Stars similar in size to our sun would be able to remain on the main sequence portion of their lifespan for approximately 10 billion years. Stars that are smaller than our sun may, depending on their size, be able to stay on the main sequence for 20 billion, 40 billion years, or even longer. Some very small dwarf stars that were born shortly after the Big Bang may actually be able to keep on trucking (main sequencing) right up to the death of the universe that scientists think may occur trillions of years in the future. Some of the giant and super-giant stars, however, are so massive that they cannot remain on the main sequence any longer than a few million years (or less). This, for us, however, is a good thing since it is the explosions (supernova) of these bigger stars that supplies the universe with the heavier atomic elements (carbon, iron, oxygen, etc.) that are needed to build planets and life (plus also create pressure waves that cause nearby gas and dust clouds to collapse and form stars and planetary systems).

Therefore, giant and super-giant stars would not be good candidates as abodes for life-forms that require longer evolutionary time periods for development. Stars that are smaller than our sun would possibly be able to provide a sufficiently long-term stable environment that even the evolutionary slow-pokes would appreciate. However, stars smaller than the sun would have continuous habitable zones that are narrower than that of the larger sun-like stars. Remember, the continuous habitable zone is the total distance from a star where things remain warm enough to allow liquid water to exist on the planet's surface. In our solar system, the habitable zone extends from just this side of the orbit of Venus to that of the orbit of Mars. A smaller star would have a narrower habitable zone which would likely decrease the chances of a life friendly planet being able to form in such a narrow corridor. Another potential problem for habitable planets orbiting small stars would be that, because of its closeness to its home star, the planet's daily rotation might be so slow that one hemisphere would always face the hot star with the other side remaining in constant (cold) darkness. This could create very extreme and unstable planetary climatic conditions that could wreak havoc with the evolution of life (at least as we know it). However, more recent "computer modeling" studies (yet another new toy for the scientists) have found strong evidence that this situation might not be such a major impediment to carbon-based life. Such planets would have large geographical zones located between their day and night sides that could provide stable and relatively temperate climatic conditions that could be quite life friendly.

Figure 5-31 - A few years ago, most astronomers believed that it would not be possible for exoplanetary systems to form around double or multiple stars. Since such planetary systems have now been found by the Planet Hunters, artist's can now paint pictures of the beautiful "multiple" sunrises and sunsets residents of such exoplanets might enjoy. (Image credit: NASA/JPL-Caltech/Keck Observatory)

Since at least two-thirds of all stars are part of binary or, occasionally, multiple star systems, astronomers used to believe that stable planetary systems would not be possible because of the continuously changing gravitational interactions among the stars and the planets. Astronomers have recently performed special computer simulation studies that suggest that some binary star systems might be able to harbor stable planetary systems. If the binary stars are close enough together, and the planetary orbits are sufficiently far enough away, the conjoint combined gravitational field of the stars might not interfere with the planets orbits. As of 2008, the planet hunters had detected and confirmed the existence of exoplanets in orbit around 20 different binary star systems and, just recently (January, 2010) even some triple star systems. If the binary (or triple) stars are quite far apart and the planetary system is situated close enough to its home star, the gravitational effects of the other star(s) might not pose any problems. Inhabitants of such systems might even be able to enjoy multiple sunrises and sunsets every day. **Figure 5-31** shows what one artist believes inhabitants of one such multi-star planetary system might be treated to in terms of breathtaking sunrises and sunsets.

What Kinds of Exoplanets Should We Search For?

In addition to the astrobiologists' preference for looking first at sun-like stars for signs of carbon-based life, the types of planets they would initially be looking for would be earth-like water worlds, like ours. While larger Jupiter-like planets could possibly have thick atmospheres containing hydrocarbon gases (with lots of life friendly hydrogen, carbon, nitrogen, etc.), their greater gravitational fields would make any upright walking critters (if there were any solid land surfaces to walk on, which there might not be) so heavy that they would have tremendous back and foot problems (if they had feet). If the Jupiter-like planets were found to be in close

proximity to their home stars (i.e., the hot super-Jupiters recently found by the planet hunters), we could probably discount the possibility of anything other than exotic hyperthermophile type life-forms. If, however, the distance of such Jupiter-size (or larger) planets were far enough away from their stars to be inside their star's continuously habitable zone, *it might be possible for them to have orbiting moons that might actually be small blue water worlds not unlike the Earth*!

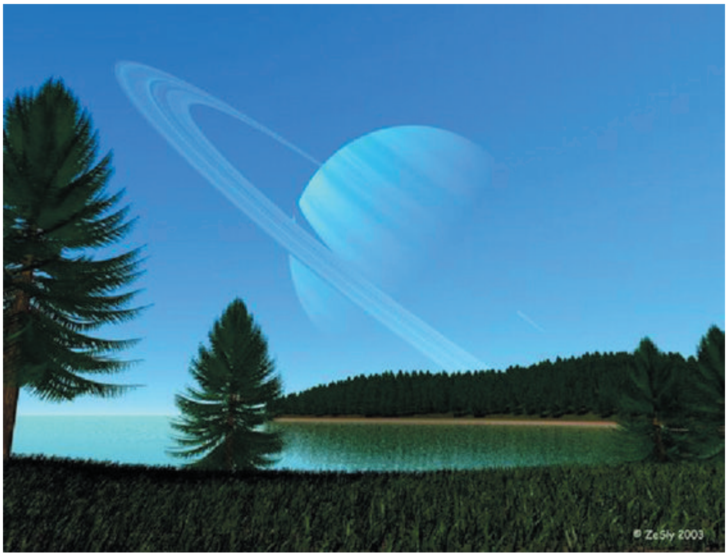


Figure 5-32 – Astronomer's now believe that, for any gas giant exoplanets that reside in their home star's "habitable zones" (and the Planet Hunters now tell us some do), their moons might harbor earth-like climatic conditions that could spawn carbon-based life. Shown is an artist's drawing of what a earth-like "moon" of a Saturn-like exoplanet might look like. (Image credit: Sylvain Girard - zesly.net)

Figure 5-32 shows one artist's attempt to illustrate this bizarre, but perhaps not all that rare, "blue moon" phenomenon. Perhaps mankind will soon have a whole new meaning for the age-old phrase *"Once in a blue moon"!*

Finally, before ending this chapter, I would like to describe the exciting story of the discovery of what many astrobiologists believe may be the first habitable exoplanet. As described above, scientists now believe that the most likely place to look for carbon-based life-forms like us would be planets (1) which are close to the same size as the earth (giant gas planets like Jupiter and Saturn would likely not only lack solid surfaces that critters could walk on, but would also have atmospheres plus strong gravitational and electromagnetic radiation fields that would not accommodate our form of life), (2) that orbit smaller stars that remain on the main sequence for longer periods of time which would allow more time for life to develop, and (3) most importantly, also orbit in their home star's continuously habitable zone where the climate would be warm enough to allow liquid water to exist on the planet's surface. In April, 2007, the planet hunters found an exoplanet that appeared to fit all three of these requirements.

There is a star named Gliese 581 located in the star constellation Libra that astronomers discovered has a small *complex* wobble in its motion through space, which suggests it has several orbiting exoplanets. This star is located just slightly more than 20 light years from us (relatively speaking, a close neighbor) and is only about one-third as massive as our sun. Because of its smaller size it puts out less heat and is somewhat red in color, and is therefore classified by astronomers as a *red dwarf* star. Stars of this size will remain on the main sequence portion of

their lives for a longer time than will our sun (lots of time for the evolution of life). Gliese 581 is now believed to be orbited by six exoplanets. The first planet discovered in 2005 (designated as **Gliese 581 b**) is a gas giant about the same size as Neptune, but is a ***Hot Neptune.*** Since its "year" (orbital period) is only 5.3 days long. It is probably not life friendly. However, what initially had the astrobiologists jumping for joy was the fact that the second planet discovered (in April of 2007), which was labeled ***Gliese 581 c*** by the astronomers, is only about five times more massive than our own earth and is orbiting in its home stars continuously habitable (i.e. goldilocks zone). Since its home star is considerably smaller than our sun, the length of the year on Gliese 581 c is only 13 earth days long. Whether this exoplanet is a rocky planet like earth or a water world completely covered by oceans is, at present, unknown. **Figure 5-33** shows an artist's drawing comparing the size of earth and Gliese 581 c. **However, the story does not end here!**

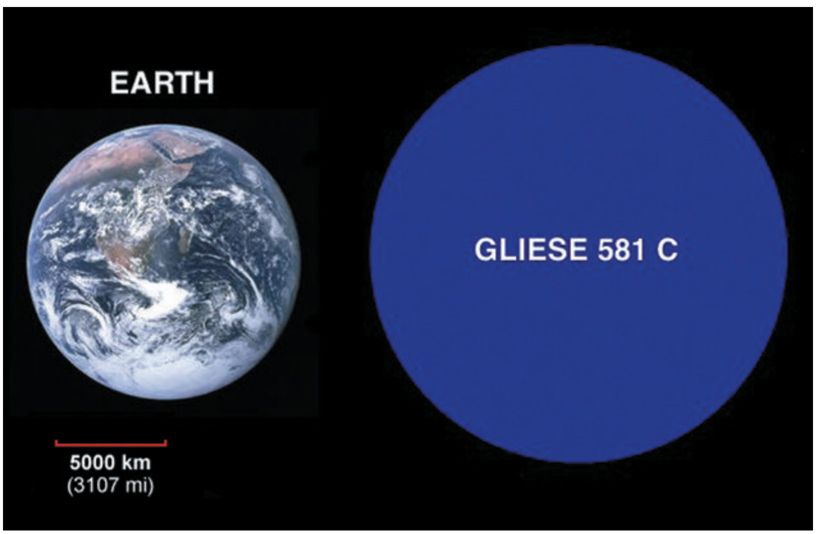


Figure 5-33 - Shows an artist's drawing comparing differences between Gliese 581c and the earth in terms of size. Until just recently, scientists believed this exoplanet might possibly be life friendly. It is now believed to be suffering from a runaway greenhouse effect which would make it too hot to support life. However, the Gliese exoplanetary system has other planets that might be life friendly. See the text for this story. (Image credit: NASA).

A short time after its discovery in 2007, Gliese 581 c was found to have a "flaw" in its makeup that, even though it is the right size and in the right location to be habitable, it probably is not habitable. Scientists discovered that this exoplanet likely suffers from a runaway greenhouse effect that makes it too hot to sustain carbon-based life. However, all is not lost with respect to the Gliese exoplanetary system's possible life friendly status. Later in 2007, a third exoplanet was discovered, ***Gliese 581 d***, that while seven times more massive than the Earth, is also orbiting in its home star's habitable zone (orbital period of 69 days) and, in spite of its somewhat larger size, could be life friendly. And just recently, In April of 2009, a fourth exoplanet was found to be orbiting Gliese 581. This planet, named **Gliese 581 e,** is the smallest of the four with a mass that is only 1.9 times greater than the earth. Unfortunately, it has an orbital period of only 3.2 days which would likely make it far too hot to be life friendly.

And now for some "breaking news"! At the time this book was in the final stages of preparation to be sent to the publisher, two more exoplanets were discovered to be orbiting Gliese 581.

The fifth planet to be discovered , **Gliese f,** is not believed to be life friendly (at least for carbon based life) since it is a little larger than our own solar system's Uranus but is located beyond the ice line of the Gliese system and, unless it harbors Europa- type moons, is probably too cold to support life. However, earlier this week (late September, 2010) a sixth planet was reported by astronomers that has quickly caught the attention of the news media. This exoplanet, **Gliese 581 g**, is also orbiting right in the middle of its home stars goldilock's zone and is only three times more massive than earth! Astronomers now believe this newly discovered planet is even more earth-like than Gliese 581 d and is now the Gliese system's new leading candidate for harboring extraterrestrial life. **Figure 5-34** shows an artist's drawing of what either of these two potentially life friendly exoplanets might look like as they orbit around their home star.

Therefore, while the planet hunters are now beginning to confirm that smaller exoplanets similar in size to the earth do exist in other parts of our galaxy, the question of whether any may be earth-like water worlds orbiting in life friendly habitable zones has not yet been totally verified. A rapidly growing number of our astrobiologists, however, now believe that in the next few years, new sophisticated planet hunting tools similar to the Kepler space telescope recently launched by NASA will provide evidence that such worlds are relatively more common in other regions of the universe than any of us would have dared imagine just a few years ago.

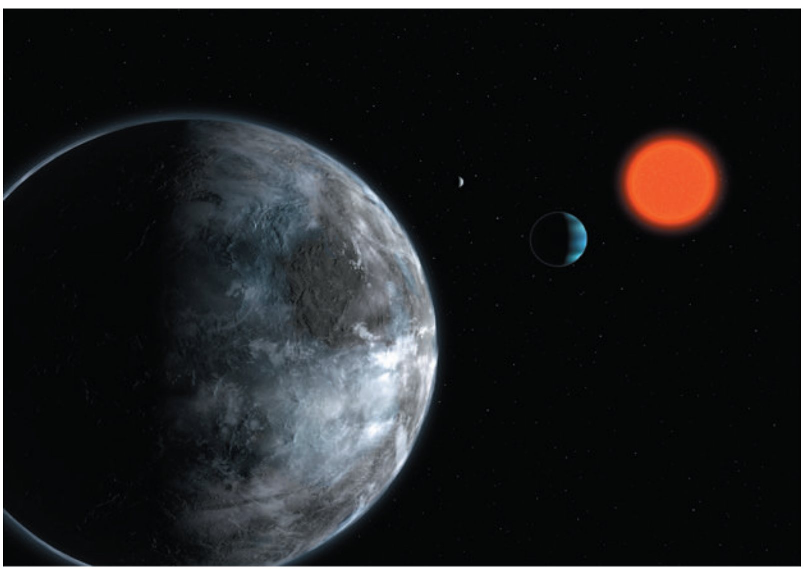


Figure 5-34 - Shows an artist's drawing of what either Gliese d or g (the two successors to Gliese 581c as the Gliese system's possible life friendly planets) might look like close-up. (Image credit: ESO/L. Calcada/Wikipedia Commons)

CHAPTER VI

THE POSSIBILITY OF VISITING OR COMMUNICATING WITH EXTRATERRESTRIAL CIVILIZATIONS

Many scientists, including the author, now believe that, in the very near future space missions like the recently launched ***NASA Kepler Planet Finder*** will begin verifying the existence of earth-like planets that are orbiting their home stars in life friendly habitable zones. This finding will constitute one of the greatest "reality checks" that mankind has ever experienced. One of mankind's oldest and possibly most profound questions of whether we are alone or not in the universe will finally be answerable. If extraterrestrial life is actually discovered, no psychologist, sociologist, or even theologian alive today can possibly predict how humans will react to this news. However, one thing is certain – a large number of us will immediately begin pressuring our NASA, JPL, and ESA cohorts to send some of us to visit these faraway worlds and begin socializing with our newly discovered neighbors. Just knowing that we are ***not alone*** in the universe will not be enough for many of us. We will want to "mingle". But, will this be possible, or will we be forced to somehow adjust to an entirely new form of solitary confinement? In this chapter, the author will try to address these important questions.

How Feasible is Interstellar Space Travel?

As we saw in Chapter 2, the extremely large distances even to the closest exoplanets outside our own solar system is such that our current space faring technology would be totally unable to send human astronauts to such locations and safely return them to Earth in a single lifetime. The fastest man has ever been able to travel in space (via American and Russian earth orbiting missions, plus the American Apollo moon landing program) is between 17,000 and 25,000 miles per hour. While this speed is sufficient to allow man to travel around the earth in a little over one hour, and to travel to and from the moon in just a few days, it is far too slow to allow for a reasonably comfortable trip when traveling between different locations (planets) even within our own solar system. A roundtrip to Mars would require a minimum of 2 or 3 years, and

one to the outer solar system (e.g., perhaps to Europa in the Jupiter system), would require the astronauts to sacrifice a big hunk of their total lifespan (perhaps 8 to 10 years). And, as for Alpha Centauri, the closest star next to our own sun, our current rocket technology might be able to get us there in a mere 80,000 or so years (a bit faster than in a jumbo passenger jet). Obviously, rocket ships that would be capable of allowing mankind to easily travel to distant locations in our solar system or even to our next door neighbors in our small corner of the universe will probably not be funded and constructed any time soon.

Another major impediment to our being able to rocket away at fantastic speeds to far away corners of the universe is the fact that most scientists today believe the universe may harbor its own inherent speed limit that we may not be able to exceed no matter what kind of fancy technology we might try to develop. Albert Einstein, many years ago, developed a formal scientific theory of space and time (known as the ***Theory of Relativity***) that states that no physical object can ever travel as fast as the speed of light, which is 186,000 miles per second. This seems to be a law of physics that holds true for the entire universe. Unfortunately, Einstein's theory of relativity, while having received a huge amount of supporting scientific evidence during the past 50+ years, is another one of those mind boggling scientific concepts that scientists have developed to explain how the universe works but which is very difficult for non-scientists to fathom. To put it simply, Einstein's theory says that the reason that no physical object (e.g., a space ship) can travel faster than the speed of light is that, as such objects approach this speed, they gradually become more and more massive until, at the speed of light, they become "infinitely" massive. Since there is not enough energy in the whole universe to keep an infinitely massive object moving, the object would completely and totally change from its material form to its alternative energy form. Remember, energy and mass are the two interchangeable forms of matter and Einstein's famous $\boldsymbol{E = MC^2}$ formula states that small amounts of mass can be converted to huge amounts of energy, and vice versa, as is done constantly each and every day inside the cores of stars.

Another very bizarre thing that happens as objects approach the speed of light is that "time begins to slow down". However, this is a relative effect (ergo the theory of "relativity"). While the crew members and their passengers inside a speeding space ship would absolutely perceive no change in time, or in the speed of their clocks, etc., their relatives back on earth, if they could look inside the space ship (e.g., with some form of "magical" remote controlled TV hookup), might see the passengers themselves physically moving around slower and slower and their clocks losing more and more time. Now, for the really bizarre end of this story - when the speeding space ship and its occupants finally turn around and return to Earth, they will themselves be only slightly older, but any relatives that are able to meet them at the spaceport will be much older, if still alive at all. Thus, with the appropriate rocket technology, it would be possible for astronauts to travel the long distances to the stars and not notice that much change in their own personal aging process. However, they would, for all intent and purposes be completely leaving their relatives and friends forever since by the time they get back from

the star trip, these people may have long ago died of old age. The reader needs to know that this strange "light speed/aging" effect is ***not*** science fiction but is a bona fide science fact, no matter how weird it seems. In the 1960s and 70s, when astronauts in Mercury and Gemini spacecrafts were orbiting around the earth at speeds of just under 20,000 miles per hour, their wives back in Houston, Texas were actually aging slightly faster than they were. This husband/wife differential aging effect, while extremely small, was real (but definitely not measurable with today's medical technology). Scientists have been able to demonstrate that clocks onboard orbiting spacecraft (e.g. the International Space Station) do, over very long periods of time, actually lose measurable amounts of time relative to earth clocks. Truth is indeed sometimes stranger than fiction![1]

Although many scientists today believe this speed of light restriction on interstellar space travel is a firm law of nature that cannot be overcome, a few scientists are quick to point out that humans, and even scientists, have always been extremely pessimistic or, to use a kinder and more gentle term, ultra-conservative, when it comes to speculating about what fantastic new discoveries may lie ahead in all fields of science. Just three months before the Wright brothers of North Carolina demonstrated on December 17, 1903, that man could fly, one such scientific expert, Dr. Simon Newcomb, who was one of the top American astronomers of the 19th century, published a journal article (Newcomb, Simon. "The Outlook for the Flying Machine." *The Independent, A Weekly,* October 22, 1903, pages 2508 to 2512) in which he stated that, short of using a lighter-than-air machine (i.e. a hot air balloon), manned flight is contrary to the laws of physics and, therefore, totally impossible. Rocket science, however, has come a long way since the 1920s and 30s when the first small noisy and extremely dangerous prototypes were being shot a few hundred feet into the air while their neophyte rocket science inventors nervously hid behind trees. However, while we now know that chemical fueled rockets can get man and his toys to the moon and back and even deliver small unmanned probes to the edge of the solar system and even beyond into interstellar space, such technology is totally inadequate for purposes of manned interstellar travel. Whole new forms of "rocket science" will be needed to solve this problem. Scientists today are, however, busy brainstorming and tinkering with new ideas that might work. Instead of chemical fuels, scientists are considering ways to develop forms of far more efficient nuclear fuel technologies (**Figure 6-1a**). Most scientists believe that, while extremely expensive, mankind might in another 100 (or 500) years, have the necessary technology to develop nuclear powered rocket ships that

[1]However, in a very real sense, any space travelers that were able to travel at speeds close to the speed of light would not only be aging at a considerably slower rate than their friends and families back on their home planet, but would also be literally **participating in time travel, i.e., "traveling into the future"**. To illustrate the miniscule size of this aging/future time travel effect, many years ago a Russian cosmonaut named Sergei Avdeyev set the world record for the longest time spent orbiting the earth in the Russian Mir space station. In three separate missions, he stayed aloft a total of 748 days. By doing this, Sergei traveled .02 seconds into the future and, at the same time set his biological clock back .02 seconds.

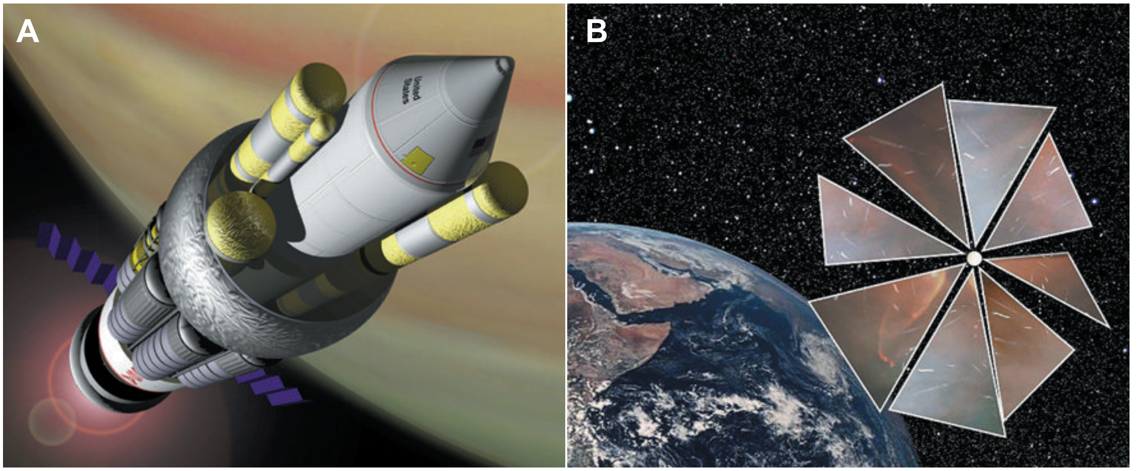


Figure 6-1 - The absolutely immense and mind boggling distances that will separate man from even his closest extraterrestrial neighbors in space definitely does not bode well for personal visits. Manned interstellar space travel is, and will likely remain so for quite some time, well beyond our technological capabilities. However, this gloomy outlook is having absolutely no effect on the best and brightest of our engineers and rocket scientists whose "never say die" attitude is spurring them forward in developing solutions to this problem. **A.** Powerful nuclear powered starships or **B** gigantic 'sailing ships" powered by solar "winds" are just two of a multitude of possible ideas these people are working on. (Image credit: NASA/Goddard Space Flight Center/John Ballentine/Wikipedia Commons)

would allow man, although not actually achieving the speed of light, to get as close as perhaps 90% or even closer to this speed. This would allow adventuresome astronauts to do round trips to our closest stellar neighbor, Alpha Centauri (which is 4.4 light years away), in possibly less than a lifetime. Taking into consideration the time needed to get up to full speed and later slow down on the return trip, a 30 year-old astronaut (who was the uncle of his sister's newborn child) might be able to get back to earth in time for both his and his nephew's 65th birthday parties. Other scientists are also busy trying to come up with even more efficient and cheaper (if not "far-out") solutions to this problem. Some scientists, who probably played with toy sail boats as children, are even considering developing and attaching incredibly huge sails to space ships and having the power of light emitted from nearby stars (equivalent to wind power on sail boats) push the spacecraft (**Figure 6-1b**). Others have even suggested building huge cannon or gun-like contraptions on earth that could shoot powerful laser beams towards the sails to push the spacecraft. (Good luck on getting the Alpha Centaurians to build equivalent guns to push us back home!) However, unless scientists can figure out a way to travel reasonably close to or even exceed the speed of light, interstellar space trips may forever remain out of mankind's grasp.

However, since many scientists are, by their nature, bizarre thinkers, some future diehard may actually find a way around this obstacle. Captain Kirk and his cohorts used "warp drives" on their starship Enterprise to do this. While strictly science fiction when first beamed to our TV sets, a few subsequent scientists are now beginning to believe that such faster than light

travel may not be impossible. Albert Einstein's theory of relativity actually leaves the door open to the possibility that future technologies might allow us to take "short cuts" through space and time. Although we earth-bound types have absolutely no means of understanding what this statement means, Einstein's theory supports the idea that, since space and time are curved and not flat it might be possible to construct special "tunnels" (which have been labeled by scientists as "worm holes") that would allow space travelers to take a short cut from one point in the universe to another location instead of "taking the long way around". This would be somewhat loosely (very loosely!) equivalent to being able to travel to China by digging a hole (tunnel) straight through the earth rather than taking the longer route over the earth's surface. Since the author is now beginning to venture far too deep into topics that are too far out to contemplate at present, I will refer the reader to an excellent popular science book (written by a respected and very knowledgeable group of scientists who definitely are not lunatics) that is referenced (S. Schmidt & R. Zubrin, reference 20) at the end of this book.

Searching for Signals Sent by Intelligent Extraterrestrials or Physical Objects left behind by ET

By the end of the 21st century, astrobiologists may possibly know whether or not any other location (planet or moon) in our solar system ever did, or still does, harbor simple forms of carbon-based life. Although it is unlikely that advanced or intelligent life-forms will be discovered, in a universe that may house as many as 100 billion galaxies, each containing as many as 100 billion stars, and where scientists now believe that significant numbers of these stars, possibly as many as 20 to 50 percent, may host planetary systems, the possibility of intelligent life-forms elsewhere definitely should not be excluded. If intelligent life is out there, how do scientists go about verifying its presence or, better yet, visiting or communicating with it?

In an earlier chapter we introduced the idea that, in the next few years, our scientists will be able to develop sophisticated new forms of remote sensing technologies that will radically improve on the astronomer's traditional and time-honored ability to visually examine and perform chemical analyses of distant celestial objects from afar. Hopefully, the development and launching of large sophisticated ***Terrestrial Planet Finder*** systems into space (or building them on the moon) will, before the end of the 21st century, allow us to perform chemical analyses (via spectroscopy) of the chemical composition of exoplanet atmospheres plus look for structural features on the surfaces (e.g., continents and oceans, or even large engineering projects built by ETs) that could suggest that at least carbon-based life-forms may be present. If we find likely candidates for such life friendly environments, what do we do next? Send manned or robotic space missions to search for life? The answer is definitely "yes" of course, but we would probably not get answers to our questions anytime sooner than our great, great, great…., grandchildren's birthdays, if mankind is still alive and kicking. Or, being the impatient

creatures we are, dare we assume that any advanced inhabitants of such exoplanets may have had enough time to avoid self-destruction and start engaging in constructive activities that mankind's technologies might be able to detect from a distance?

The first technology that mankind developed which we know can be easily detected from incredible distances in space is radio and television. This very simple and basic form of communication technology might also be one of the first that extraterrestrials might also develop. The technologies related to radio and television forms of communication have been available to mankind since shortly after the turn of the 20th century. The supposed inventor of "wireless telegraphy", i.e., "radio" was Guglielmo Marconi who, in 1901, successfully sent the first transatlantic radio message. The first functional prototype of a black and white television set was actually built in 1926. Add to this the virtual explosion of the commercial use of these electronic mediums starting in the late 1940s (plus the addition of radar systems during WWII) and mankind has now been inadvertently leaking electromagnetic signals into space for quite some time, and these signals are all traveling at the speed of light. Because of their non-directional nature, these signals have been getting weaker and weaker the further out into space they travel. However, they could still possibly be detectable by extraterrestrial eavesdroppers as far away as our closest stellar neighbors, including the Alpha Centauri system, or even further. The amazing thing about television and radio (plus radar) forms of electromagnetic signaling is that the technologies involved are relatively simple and inexpensive. Man himself was able to develop this technology just a few short years after he switched from riding horses and pulling wagons to polluting the atmosphere with automobile exhaust fumes. And, perhaps most important of all, is the fact that the wavelengths in the so-called radio portion of the electromagnetic spectrum are not only cheap and easy to send and receive, but can also be sent over huge distances without being significantly interfered with or blocked by interstellar matter such as gas or dust clouds. Man now has the technology to send and receive radio signals from the other side of our own galaxy or even further.

In the early spring of 1960, a very young Frank Drake, who had just completed his Ph.D training in astronomy, came up with the idea that listening for radio signals from ET might be a great way to launch his research career. He approached his new bosses at the Green Bank Observatory in West Virginia who gave him permission to point a newly constructed radio telescope in the direction of some nearby sun-like stars and listen for possible radio chatter from "little green men". In the present author's opinion, Dr. Drake's research idea was an absolute "no brainer" in terms of sound scientific decision making, in spite of the fact that it probably elicited a few "giggles" from some of his friends and associates. Mankind had now mastered this primitive (but quite effective) communication technology, and perhaps some extraterrestrials may have also reached this same developmental milestone. Some critics have argued that using today's radio technology may not be a good choice since, as communication technologies advance, we will before long stop using our outdated primitive tools and switch to more leak-proof alternative (e.g., fiber optics) technologies that are far more efficient and

cheaper (Plus, *duh,* totally different from anything our best scientific minds today can conceive of!). Such advanced communication techniques would likely not be detectable from space. However, the present author, if he were a little green life-form who was curious as to whether there was anybody out there to communicate with, would likely select the easiest, cheapest, and most effective communication tool available, which, although "primitive" might also be the first tool that extraterrestrials would stumble onto, and, therefore, possibly be (at least initially) the most widespread and easily available means of announcing their presence and opening up possible interstellar dialogues. Any extraterrestrial civilizations more advanced than man's present level, even after having gone on to develop those exotic and more efficient means of interstellar communication (which we earthlings may not discover for many years or centuries to come) might still opt to first try (*or also try*) communicating with our current primitive technology simply because this might give them a larger audience to talk to.

For two months, Frank Drake conducted an intense marathon to listen for possible radio signals from extraterrestrials (**Figure 6-2**). For long hours at a stretch and virtually every day and night, Frank pointed his radio telescope at two nearby sun-like stars. The very first night he started listening, Frank did actually pick up a clear loud signal. Unfortunately, he later discovered that this rogue signal had probably originated from an aircraft flying overhead. For the remainder of his listening marathon, Dr. Drake heard nothing that could have been sent by ETs. However, rather than being disappointed, Dr. Drake was elated in knowing that mankind's most intellectually and possibly spiritually satisfying scientific quest was now underway, i.e., the ***search for extraterrestrial intelligence (SETI)***. Following Frank Drake's "failed" ET search in West Virginia, other scientists quickly realized the value and potential importance of this new scientific venture, and started coming out of the woodwork worldwide to join in the new exciting search for life elsewhere in the universe. Similar search programs were quickly established at radio telescope facilities in other parts of the world. Again, because of space limitations in the present book, I will refrain from presenting a detailed historical narrative of the last 50 years of SETI research but instead defer the reader to an excellent book referenced (Gloria Skurzynski, reference 22) at the end of this book.

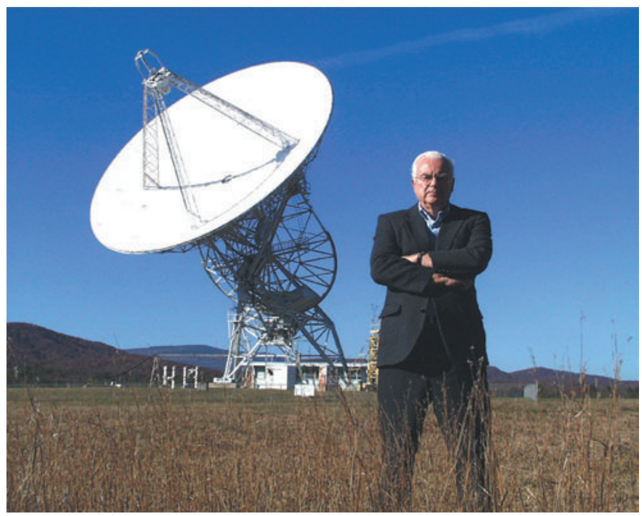


Figure 6-2 - In 1960, a very young Frank Drake, Ph.D, became the first scientist to take a radio telescope and try to listen for possible radio signals that extraterrestrials on distant exoplanets might be trying to send our way. Shown is Dr. Drake standing in front of the radio telescope he used for the world's first scientific search for ET. (Image credit: National Radio Astronomy Observatory/National Science Foundation)

Initially, the biggest problem that the early SETI researchers faced was determining where on the radio dial to listen. The long wavelength or radio portion of the electromagnetic spectrum is, as anyone familiar with car radios knows, extremely crowded with a potentially large number of separate "stations" from which we can set the dial and listen. Scientists refer to these small sections of the extremely ***broad*** (i.e., wide) bandwidth of the entire electromagnetic spectrum (see Figure 2-10) as the ***narrow*** bandwidth within which the communication signal is being transmitted. Commercial radio and television stations on earth are each assigned a narrow bandwidth (which is identified by the location of the narrowband channel relative to the larger electromagnetic spectrum, such as, for example, 100 megahertz) by a government regulatory commission and told to only transmit signals that fall within this bandwidth. However, the problem that scientists (or extraterrestrials) face when selecting regions of the radio spectrum to tune into for possible artificial but intelligent signals from distant sources in interstellar space is that they would need, because of the nature of such potential signals plus the universal laws of physics, to use incredibly narrow bandwidths. Instead of bandwidths as wide as 100s or 1000s (or millions for television signals) of cycles per second (hertz) that are commonly used by commercial radio and television stations, they would need to choose bandwidths as narrow as only a few hertz, or even less than 1 hertz. Thus, when the SETI investigators started pointing their radio telescopes at some star and listening, they potentially would have had billions and billions of potential bandwidths (stations) from which to choose. After scratching their heads for awhile, the early SETI scientists decided to initially focus in on narrowband channels in a region of the electromagnetic spectrum that (1) contained the smallest amount of potentially interfering background radio noise and which (2) was also close to the spectral region where the atomic elements that make up water (hydrogen and oxygen, or actually the hydroxyl radical OH) emit their own natural radio frequencies. Since water (H_20) is the primary ingredient of carbon-based life, the SETI scientists thought that other carbon-based life-forms might also logically focus in on this same "water hole" region of the radio spectrum. It is, of course, a bit of a stretch of the imagination to think that little green men might think like us and see this spectral region as a "natural gathering place" for all sorts of critters that shared the same need to consume water to survive. Humans are, by nature, extremely prone to assign human qualities to non-human critters (if you don't believe this, ask your family pet).

Fortunately, thanks to the rapid advance of computer technology, this "which channel to listen too nightmare" is quickly disappearing. Because of high speed digital computing, today's radio telescopes can literally listen to millions or billions of extremely narrow bandwidth channels at one time rather than the much smaller number that Frank Drake could listen to in 1960. And since computer processing speeds are still doubling every 18 months, we can expect that future SETI searches will get more productive, easier, and cheaper. It is absolutely true that, since the advent of the first radio telescope searches in the 1960s, SETI scientists have only been able to look for an incredibly small needle in an incredibly huge haystack. SETI's "failure" so far to identify actual evidence of communicating extraterrestrial civilizations,

however, has made it virtually impossible to obtain government research funds to support their work. A nice sized NASA government funded program that had begun in the 1970s was canceled in 1993. Subsequent SETI research has had to rely on private donations from ordinary citizens plus the generous support by Paul Allen, the co-founder (with Bill Gates) of Microsoft, Inc. Because the SETI researchers have had to move forward without government funding, they have been forced to become quite ingenuous and assertive in pursuing their work. For several years now, SETI has been affiliating themselves with established radio telescope observatories in order to collect their raw data. When the radio astronomers are doing their normal (and funded) radio telescope work, the SETI scientists use a special "black box" that they built which can be easily attached to the radio telescope which then allows the scientists to continuously collect and record potential signals from ET. Since SETI would, at this point in history, have no means of knowing where the extraterrestrials live and which locations in space might be better for purposes of eavesdropping, this piggyback arrangement is working just fine. At present, the biggest problem facing the SETI researchers is not in the actual collection or recording of raw data, but in the detailed analyses that the data must be subjected to in order to determine whether or not it may contain a bona fide extraterrestrial message.

One of the current SETI projects involves a collaborative effort between the world's largest radio telescope (see **Figure 6-3**), which is located in a remote part of Puerto Rico, and the astronomy department at the University of California, Berkeley. While the Arecebo radio telescope is busy performing its other assigned research tasks, SETI has a little "black box" attached to the telescope that is busy recording radio emissions from wherever in space the system is pointed. This data is recorded on computer tape and then delivered to the Berkeley astronomers. At the present time, the SETI scientists are collecting and recording far more piggybacked data from the Puerto Rico telescope than they have the computer resources needed to keep ahead of the complex data processing that is required. The data sent from the Arecebo telescope by the SETI scientists is continually

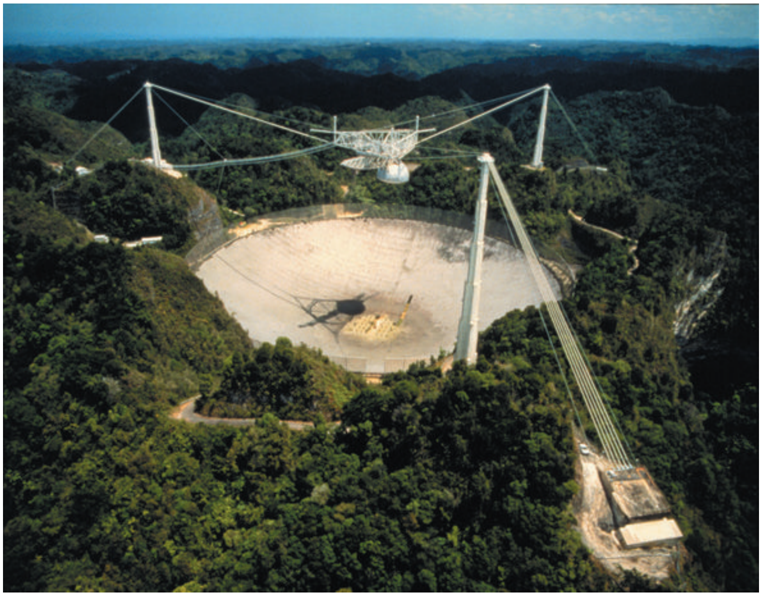


Figure 6-3 - Prior to the advent of the computer age and before anyone had come up with the idea of linking many small radio telescopes together to function as a single huge radio telescope, astronomers were building gigantic radio telescopes. Shown is an aerial photograph of the world's largest such radio telescope, the Arecebo telescope located in Puerto Rico. (Image credit: NASA)

(digitally, of course) sliced up or boxed up, whatever, by the Berkeley scientists into small data packets and then sent, via the worldwide web, to personal computers (pcs) located in back rooms, offices, and kitchens of private citizens all over the world. Each of the pcs has a special software program, named ***SETI@HOME.Com*** installed on its hard drive. This program is provided (and down-loaded) free of charge to any pc owner who has volunteered to allow their system to analyze radio telescope data whenever they are not online (on a coffee break, bathroom break, walking the family pet, taking the garbage out, etc.) and their computer is sitting idle with nothing to do. The SETI@HOME project was launched in 1999 and very quickly attracted worldwide attention that triggered a flood of private citizens to volunteer their pcs for the project. As of 2009, close to 300,000 pcs worldwide have the SETI data analysis programs loaded and many are actively performing data analyses for up to several hours each day. Computer scientists refer to this form of "shared computing" (linking multiple individual computers together) as "parallel computing" or the development of one ***giant and fast super-computer system***. ***Believe it or not, this SETI super-computer is presently among the top ten most powerful super-computers in the world***, and the price tag it came with is not bad either! Whenever any pc completes the analysis of a "data packet' that it received from Berkeley it sends it back to Berkeley and then is given another data packet to work on. The present author has his own pc configured with this software, and is crunching numbers for the SETI scientists 24/7 each week except when writing this book or attending to other personal computer chores. The SETI@HOME.com software package even comes with a computer screen saver that shows a colorful display of the ongoing analyses being performed on the current data packet (**Figure 6-4**). This feature provides a neat show-and-tell means with which to impress your neighbors and friends (plus an excuse to protect your pc from playful grandchildren).

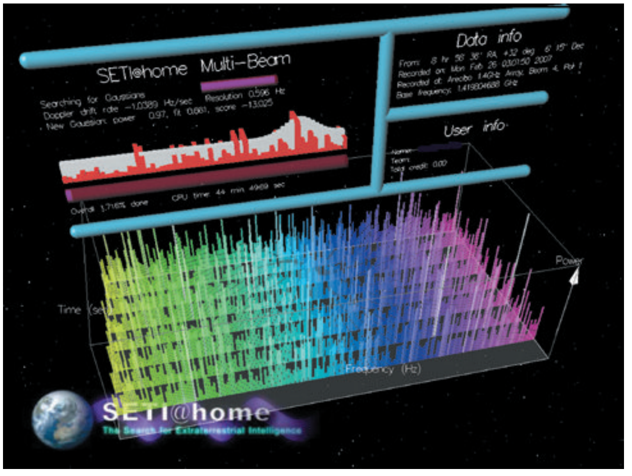


Figure 6-4 - The SETI scientists are not only linking many smaller radio telescopes together to mimic single very large telescopes, they are also linking millions of personal computers around the world to mimic single huge super-computers. SETI has developed a technique of splitting up the vast amounts of radio signals being collected by the Arecibo and other radio telescopes into small data packets that are sent to personal computers all over the world to be analyzed. Shown is an image of the screensaver that runs on every one of those pcs whenever it is analyzing the radio signals to see if ET is trying to contact us.(Image credit: Namazu-tron/SETI Institute)

Although the SETI radio astronomers have not yet identified any signals that can be confirmed as originating from extraterrestrial civilizations, almost all are optimistic that this will eventually occur. The initial "needle in a haystack" problem that haunted the SETI scientists in the early days of the project is rapidly dissipating as computer technology continues to become cheaper, faster

and more powerful. Today's SETI scientists (as of 2008) are able to collect many million times more data in a single night's observing session than was possible when Frank Drake launched the first such search in 1960. The next step in the SETI adventure will be to completely switch from being forced to collect data from other large radio telescopes in a piggyback fashion and to develop an independent radio telescope facility that can be primarily devoted 24/7 to SETI searches. Thanks to the generous support of Paul Allen, and to innumerable donations from private citizens worldwide, this next step is now moving forward. The SETI Institute (which is located in Mountain View, California and has been the home base for part of the SETI project since 1984) is in the process of constructing a dedicated SETI radio telescope facility in a relatively sparsely populated region of northern California located 300 miles north of the SETI Institute. The ***Allen Telescope Array (ATA)*** as it is called (in honor of its major benefactor, Paul Allen) will contain, in a large field, a special interconnected array of 350 separate small radio telescopes (**Figure 6-5**). Each telescope will feature a receiving dish (for collecting radio signals) that measures 20 feet across (Much smaller than the 1000 foot wide receiving dish on the Arecebo radio telescope in Puerto Rico!). While, as of 2007, 42 such dishes had been installed and are now operational, the completion date for the final array of 350 dishes is anticipated to be sometime after 2010, depending on funds becoming available. The idea of using a large number of smaller interconnected receiving dishes rather than one gigantic dish (e.g., the Arecebo radio telescope) is based on the concept of ***Interferometry***, which I discussed earlier in Chapter 5 related to building and launching *Terrestrial Planet Finder* systems. By the end of the 20th century scientists had learned that the resolution or sensitivity of a single very large radio telescope collection dish (or telescope mirror) could be closely matched by a large

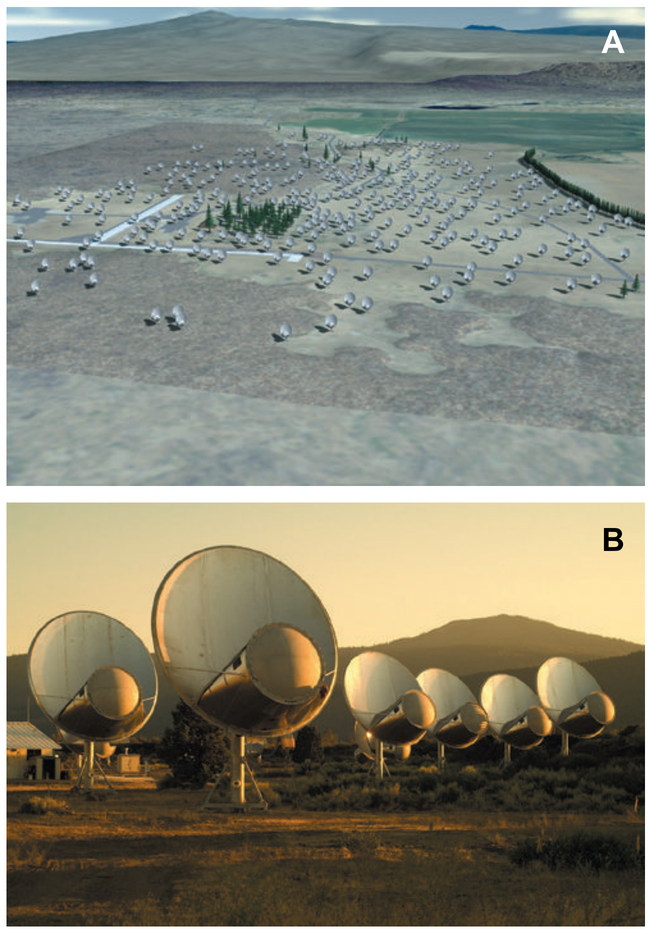


Figure 6-5 - **A** Shows an artist's drawing of what the Paul Allen radio telescope array will look like from the air (Image credit: Isaac Gary/ SETI Institute) when the construction project is completed, plus (**B**) what each of the 350 individual smaller radio telescopes will look like. (Image credit: Seth Shostak/SETI Institute)

number of spatially separated smaller collection dishes if high speed computers are used to perform special analyses on the combined information collected by each of the smaller dishes. And, of course, many small mirrors or dishes are much less expensive to construct than one super king-sized one.

The reader has probably, at this point in his/her reading, begun to ask themselves the question of whether two-way radio communications would even be possible with extraterrestrial civilizations given the restraints of the speed of light thing. Even the closest exoplanetary systems discovered to date are many light years away from us. If the Alpha Centauri triple star system, which is literally our next door neighbor in the Milky Way galaxy, had exoplanets (*No such planets have thus far been found!*) inhabited by intelligent life-forms, it would be extremely difficult to carry on two-way radio communications. Alpha Centauri is 4.4 light years away. If our scientists were to send an "Anybody home?" message, it would require 4.4 years for the query to get there, and another 4.4 years for any inhabitants (who might be listening) to send back a "Yes, how are you?" response. Thus, any two-way chit-chats with our Alpha Centaurian neighbors would be constantly interrupted by 8.8 year-long periods of deafening silence! And things would be even worse if we wanted to start up radio dialogues with any possible inhabitants of any of the other 490 or more exoplanets our planet hunters have thus far discovered. Even Gliese 581 g, which, as described earlier in chapter 5, is currently considered by astrobiologists as being the front runner for possibly harboring life, is slightly more than 20 light years away from us. Those deafening silent gaps in any two-way dialogues with intelligent Gliesians would be 40+ years long. So, it would appear that, if mankind wants to effectively communicate with extraterrestrials, it will be necessary to very patiently (perhaps the biggest understatement in the present book) develop a whole new form of one-way extended communications. We would hope that, if we ever do pick up an intelligent extraterrestrial signal that it be a bit more than a mere brief announcement of "we are here" and instead be a long extended transmission of their entire encyclopedia of knowledge (science, technology, and culture) preceded, of course, by instructions on how to break their communication code. Mankind, of course, would need to do likewise in order not to be viewed by our alien friends as socially impolite or inept.

In addition to listening for signals from ET in the radio portion of the electromagnetic spectrum, scientists have more recently started considering looking for light signals or beacons from exoplanets. During the last half of the 20th century scientists developed a means of sending beams of intense light over huge distances and keeping them sharply focused all the way to the beam's target. The military element in our society, unfortunately, immediately jumped on these so-called ***laser beams*** as a means of killing our foes and intimidating our adversaries. However, if an intelligent race of friendly extraterrestrials on an exoplanet in the Alpha Centauri system had this technology, they could beam a series of very short duration but powerful light flashes towards earth and we, with the right relatively inexpensive equipment, would be able to detect a blinking light beacon. By making each of the light pulses extremely short, perhaps no more than a billionth of a second in duration, the Alpha Centaurians would be able to generate and

send concentrated packets of light energy that, during the brief time they were turned on, would totally outshine all three stars of the Alpha Centauri system.

Therefore, today's SETI scientists have available two relatively effective and inexpensive tools for possibly identifying intelligent signals from ET – radio signals and laser light beams. Scientists using the newer laser beam technique are still using the piggyback method for detecting such signals. These scientists, like their radio SETI cohorts, have installed small black boxes on the sides of large optical telescopes that are able to continuously detect and record any laser signals that occur while the astronomers go about their normal (and, of course, funded) astronomical tasks. Since spontaneous laser like electrical artifacts can be expected to occur at least once a night, the new optical SETI investigators always have two independent black boxes set up and operating on the same telescope or, better yet, on two separate optical telescopes located many miles apart. While occasionally getting excited over the detection of such annoying artifacts, the optical SETI people have thus far, like their radio SETI friends, failed to find any signals that are believed to have extraterrestrial origins. And, of course, since such light signals or beacons would travel at the speed of light, the use of lasers as a form of interstellar communication would also carry the same limitations and frustrations as radio with respect to carrying on any two-way communication exchanges with our alien neighbors.

However, if intelligent life-forms exist on distant exoplanets in our galaxy (or even beyond), it is possible that, in addition to sending radio, laser, or other forms of communication signals our way, some may have already personally visited our planet or at least sent "unmanned" robotic machines to study us and report back to their home planet. If extraterrestrial civilizations have sent manned or unmanned missions to earth they might have accidentally or deliberately left some identifiable physical artifact behind that our technology might recognize as "probable alien" in origin. In the movie *2001: A Space Odyssey* such aliens left some kind of monitoring device sitting on the moon to track the development of life on earth and send data back to their astrobiologists. The closest mankind has come to sending such physical artifacts or "calling cards" to any location outside our solar system occurred when two NASA robotic missions (the NASA **Pioneer 10** and **11** missions) launched in 1972 and 1973 to explore our outer planets were, a little over 11 years later, able to totally and forever escape the gravitational clutches of our solar system and continue their journey into interstellar space (**Figure 6-6a**). Both of these missions carried special gold-plated plaques attached to the sides of the spacecrafts containing diagrammatic pictures of humans and even a map showing earth's location in the Milky Way galaxy (**Figure 6-6b**). Two later unmanned NASA missions (**Voyager 1** and **2)** launched in 1977 carried phonograph records (complete with a cartridge and stylus plus "playing instructions"). The records contained samples of our music plus information about our genes and brain, plus something about our lifestyles and libraries. Both Voyager spacecraft are now well beyond the orbits of Neptune and Pluto and expected to totally leave our solar system sometime in 2015. Both Voyagers are now traveling at a little over 39,000 miles per hour (or close to a million miles per day) and, unless sometime in the far distant future they fall into the gravitational

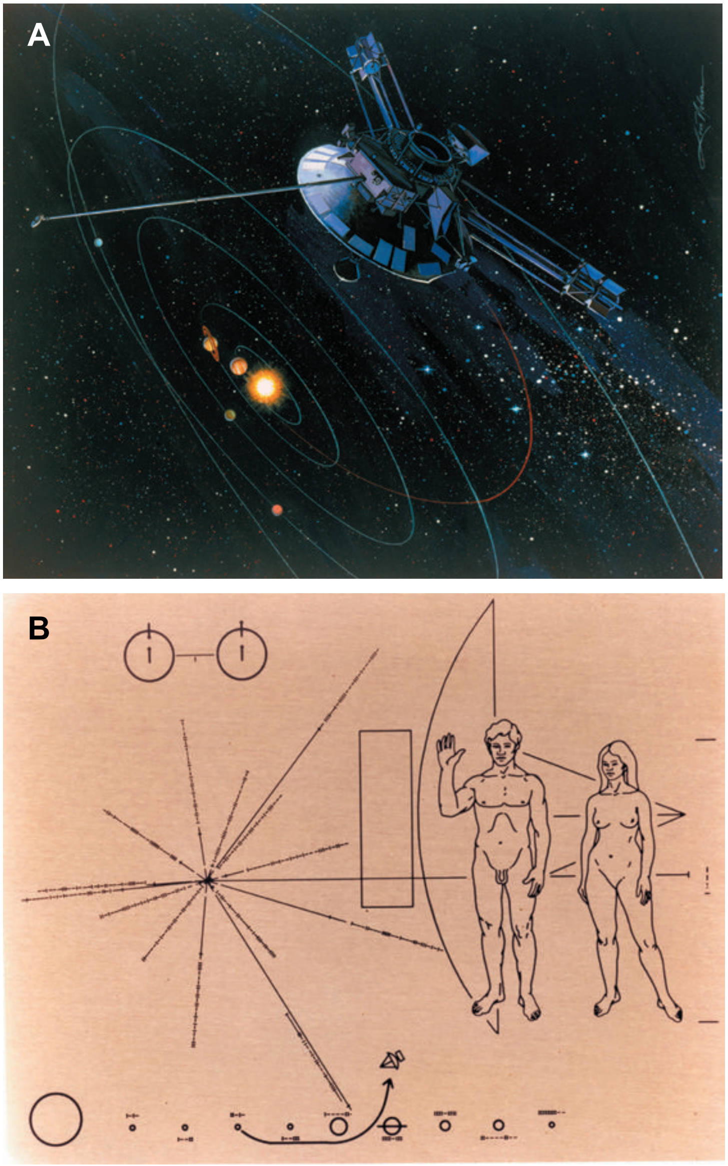


Figure 6-6 - **A** shows an artist's drawing of one of the two Pioneer unmanned spacecrafts that were launched in 1973 that have now left our solar system on a leisurely journey to the stars. **B** shows a copy of the gold plaque ("calling card" for ET) that was attached to the outside of the two spacecrafts. (Image credit: NASA/JPL-Caltech)

clutches of another star system, this speed will never change. Although the spacecrafts are not aimed at any particular interstellar location, it would take close to 50,000 years to reach even the closest star (the Alpha Centauri system). The chances of any extraterrestrials ever listening to Chuck Berry singing is, therefore, quite low.

However, it is possible that previous visitors or machines from other planetary systems could have left physical artifacts behind. Being a "litterbug" may very well be a universal feature of advanced life-forms everywhere. Of course, if this littering was accidental (unintentional?), scientists would have absolutely no way of knowing where to begin searching for such space junk. However, it is entirely possible that such physical artifacts could have been left in a specific location that the extraterrestrials believed we would search. Astronomers tell us that there exist five specific locations in space, known as ***LaGrange points***, which are relatively close to the earth and the moon where the gravitational fields of the earth and moon effectively cancel each other which allows any permanently placed object (e.g., a small artifact "parked" by ET) to forever remain stationary relative to the positions of the earth and moon. The small object would continuously rotate with the two larger objects. This effect is analogous to what happens when a communications satellite is placed a distance of approximately 22,000 miles above the

earth. The satellite would orbit the earth in the exact same amount of time as required for one complete rotation of the earth (24 hours) and forever remain in a fixed stationary orbit directly above the same spot on the earth's surface. A few astronomers have pointed their telescopes in the direction of these LaGrange points to look for any stationary objects that might be reflecting light from the sun (or the earth or moon). Of course, the smaller the object is, the dimmer it would appear. Astronomers now believe that, if such objects are reasonably reflective and as large as a small automobile, we would have been able to see them. Still, other scientists believe it would be worthwhile to either take another look with more powerful telescopes or have our astronauts take a side trip to these locations during one of their regular space missions.

The Enigma of the Flying Saucers (UFOs)

The author will now spend some time opening what some people consider a "can of worms" and provide an overview of possibly one of the most controversial, emotion-stirring, but potentially important scientific questions of the 20th century (and many believe the 21st century as well). ***Is planet Earth being visited by extraterrestrials from other worlds?*** Pollsters worldwide have, for the past 60 something years, been telling us that the majority of the world's general population think we are. Several extensive and reasonably well-conducted public opinion polls performed since the early 1950s have found that anywhere from 56% to 70% of people worldwide think UFOs are real and probably originate from extraterrestrial sources. Of course, poll data does not make scientific data. Much of the world's population also still does not believe man evolved from lower animals. Many scientists say "yes" when asked anonymously or in private whether they support the possibility of extraterrestrial visitors, but "no" if asked the same question in a public forum. In spite of burning Giordano Bruno (see Chapter 2) at the stake in Rome in 1600 for indicating he believed in the existence of living creatures on worlds other than our own Earth, the official Vatican opinion today is that the existence of extraterrestrial life does not conflict with Roman Catholic Church doctrine. Most of the world's other major religions also share this same opinion.

Following WWII, when strange unidentified flying objects (later to be called ***UFO***s, pronounced "you foes")[2] began popping up in the skies all over the world, the official positions of most of the world's governments was a strong public "no" to the question of whether UFOs might be spacecraft from other worlds. However, the fact that most countries proceeded to conduct extensive classified (secret) national security related investigations into the UFO phenomenon indicated that the private stance of many government and military leaders might

[2]The early investigators of the UFO phenomenon very quickly started using the term "unidentified flying object" to avoid the use of the term "flying saucer", which besides being somewhat incorrect, had also triggered a "giggle factor" response with the news media and a substantial portion of the general population.

possibly have leaned to the "yes" side of the issue. The definite and strong rush to investigate response of the United States government appears to have been especially puzzling considering this public stance. Many accidentally leaked documents or statements of high level U.S. government officials have subsequently surfaced which provide evidence of the wide chasm between many officials' public and private opinions on the nature of the UFO phenomenon. While Cold War paranoia involving fears of possible secret Soviet military activities was most likely a major contributor to the U.S. government schizoid response, why it is still with us in the post-cold war era remains a mystery. Even today, in order to access some of the classified investigation files on UFOs one must possess a "top secret" clearance from the United States government. Many foreign governments, including those of France, Belgium, Chile, and Peru among others, have in recent years been trying unsuccessfully to persuade the U.S. to join them in a more public and declassified form of UFO investigation.

While many government officials/employees continue even today to publicly discount the legitimacy of the UFO phenomenon as deserving serious investigation, many private citizens from many countries have stepped forward to urge that such investigations are needed. Many of these individuals, who label themselves as ***Ufologists*** (i.e., UFO investigators) hope that the tools of traditional science can be used to resolve the mystery of the UFO phenomenon. Many respected space scientists, who believe that in a universe as vast as ours life elsewhere is quite probable, will also say "no" to the question of possible visitors from space simply because they believe the horrendously long distances such visitors would have to travel would make such a venture, if not impossible, at least far too expensive and time-consuming to justify the effort. And, of course, the "lunatic fringe" members of the Ufology group (who are, fortunately, in the definite minority of this group) always respond with a loud and clear "yes" to questions of possible extraterrestrial visitors. These "true believers" accuse the U.S. government of pursuing an intense cover-up including hiding crashed flying saucers plus the frozen corpses of their crews in secret warehouses. These latter individuals are a major reason any serious attempts to investigate UFOs is shackled with a huge public giggle factor and is ignored by many main stream scientists and government research funding agencies.

Starting in the last days of WWII, fighter and bomber aircrews (both Allied and Axis) began seeing and tracking strange metallic or glowing objects flying close to their aircraft. At first thought to be secret weapons of the other side, such "foo fighters or "kraut balls", as they were called by the Allied aircrews, while exhibiting definite signs of being under some form of intelligent control did not appear to be hostile in any way. Shortly after the end of the war, strange flying cigar shaped objects started being seen by people in the Scandinavian countries. At first, these UFOs were thought to be tests of captured German V2 rockets being conducted by Russian scientists, but this was later determined not to be the case. There then occurred a brief hiatus of UFO reports until the summer of 1947 when they started up once again. In the early afternoon of June 24 of that year, a businessman named Kenneth Arnold was flying his private plane near Mt. Rainier in Washington State when he observed nine brilliantly bright

crescent shaped metallic objects flying a few miles off to one side of his plane. He estimated their speeds to be close to 1,200 miles per hour, which was much greater than any known conventional aircraft (even the newly developed military jet planes) could achieve at that time. In a later interview with a newspaper reporter Arnold indicated the strange objects appeared to be moving along in a fashion similar to that of a saucer or dinner plate being skipped over a surface of water. The reporter unfortunately tried to inject a bit of humor into this strange event and labeled the flying objects as "flying saucers" in his newspaper article. This term was immediately adopted by the news media and general public and is today still the most commonly used label for these objects.

Kenneth Arnold's sighting of flying saucers in 1947 was just the beginning of what would, over the next 60+ years become a continuing series (or what has been labeled by some as "wave-after-wave") of additional sightings of these strange objects. The sightings, which have been observed worldwide (including even over the North and South Pole regions) have continued up to the present with the most recent event taking place on the afternoon of November 7, 2006 at O'Hare International Airport in Chicago, Illinois. As a passenger jet was being pushed back from the loading ramp of the United Airlines Terminal building, a group of 12 people, including pilots, mechanics and managers from United Airlines witnessed a metallic disk-shaped object hovering directly above the departing airliner. The clearly observed UFO accelerated straight up through the overcast sky, leaving a hole in the clouds. When the incident was reported to the Federal Aviation Administration (FAA), this agency refused to investigate it and dismissed it as a weather phenomenon.

The present author cannot, short of writing an encyclopedic collection of additional books, go into any kind of detailed description of what has now amounted (by numerous official and unofficial estimates) to be, combined from all of the world's countries, possibly as many as 50,000 separate filed reports (i.e., written or taped descriptions obtained from eyewitnesses by reasonably competent interviewers such as police, military personnel, or even scientists). Instead of presenting a detailed historical account of the UFO phenomenon, which would be far too much information for the reader, I will attempt to provide a brief overview or list the major features or characteristics of the UFO phenomenon as it relates to the primary purpose of this book, which is to provide the reader with a clear but fairly complete picture of where scientists are today with respect to their exciting task of investigating how life evolved on our planet and how (and where) life may be able to evolve on other worlds in the universe. The possibility (however remote it may be) that some UFOs may be spacecraft either piloted or sent by advanced life-forms from other worlds is definitely germane to the theme of the present book. I would like to state up front that, as a scientist myself, I would never, without irrefutable scientific evidence, commit to having a "belief" that some UFOs are piloted by living or mechanical ("autopilots/computers") extraterrestrials. In my many years as an amateur astronomer, I have witnessed numerous so-called "UFOs" (i.e., unidentified flying objects) that I had no clue as to what they were, but have never witnessed any aerial phenomena that I would

label as a "probable" or even "possible" extraterrestrial spacecraft of some kind.[3] However, the author does believe that what makes the UFO phenomenon worthy of serious scientific investigation are the ***overwhelming numbers*** involved. ***Far*** too many strange objects have been seen, photographed, or tracked on radar ***far*** too many times, in ***far*** too many locations on Earth, and by ***far*** too many reasonably competent observers for us to label it as being unworthy of serious study. Although many books on UFOs are too busy reporting one eyewitness account after another to make them useful for general readers, and others are too "far-out" to consider recommending for any reason other than mindless entertainment, I have cited one book by Don Berliner (reference 4) at the end of the present book that interested readers might find informative. This book, whose publication in 1995 was financially supported by Laurance S. Rockefeller, was compiled by Don Berliner in collaboration with three legitimate Ufology investigative groups (Center for UFO Studies, Fund for UFO Research, and the Mutual UFO Network) to serve as a serious "briefing document" on the UFO phenomenon to be distributed to members of the U.S. Congress and other world leaders to attempt to obtain their support in possibly obtaining government funds to investigate UFOs.

What it is about the UFO Phenomenon that might make it worth Scientific Investigation

The author would be the first to admit that the UFO phenomenon, unlike many earlier mysterious or poorly understood natural phenomena (earthly or celestial), suffers from a paucity of confirmed scientific data, and is haunted by an unusually large degree of misinformation masquerading as legitimate science. In this overview of the subject, I will try to only present UFO related information that is reasonably supported by legitimate historical or scientific evidence. The major types of evidence that has accumulated during the last 60+ years which I believe would justify a concerted scientific investigation of the UFO phenomenon is listed next:

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[3]However, the author has not been "immune" to the UFO phenomenon. As a teen-ager in the 1950s, I once was able to "squash" reports of a UFO lurking in the skies over Wichita, Kansas. For several successive days, many people in the Wichita area had been spotting and reporting UFOs to the local radio stations and McConnell Air Force Base. A little after dusk one evening, a local radio station began reporting the presence of a bright shiny object high in the western sky. I sat up my astronomical telescope and took a look at it and confirmed that it was a Skyhook weather balloon reflecting the last rays of the setting sun. I then telephoned the radio station and told them what I observed. They announced it over the air, and the calls to the station ceased. During a subsequent wave of UFO sightings over Wichita, the author remembered having read in a science book that UFOs had been reported to produce electromagnetic interference that killed car engines. I built a flying saucer detector which consisted of a magnetic compass in which the compass needle was attached to wires that were in turn attached to a lantern battery and a small electric doorbell. If electromagnetic interference from a passing flying saucer were to make the needle point away from true north, it would close the electrical circuit of the detector and make the doorbell ring. My flying saucer detector sat quietly 24/7 on my parent's back porch for several weeks (until the battery died) without ever once detecting a flying saucer.

Large numbers of UFOs have been repeatedly reported worldwide for over 60 years beginning with the end of WWII. The phenomenon has been reported in 150 countries and near large metropolitan centers in North America (Canada, United States, Mexico), as well as Central and South America, the British Isles (England, Ireland, and Scotland), many of the Republics of the former Soviet Union, Western Europe (Spain, France, Germany, Belgium), the Scandinavian countries, Asia (China, Japan, India, South Korea), and in the southern hemisphere (Australia, New Zealand, and Africa), plus also at both the North and South polar regions. UFOs have been seen near civilian nuclear power stations, at military bases in the U.S. and other major countries, at major airports (most recently O'Hare in Chicago), and in space by Astronauts and Cosmonauts.

While some reports of UFOs have been hoaxes, and others misidentifications of common objects (balloons, stars, meteors, cloud formations, etc.), a very large number of sightings have been made by reliable individuals whose experience and training should minimize such errors. UFOs have been reported by scientists (including physics professors, astronomers, space scientists, aeronautical engineers) air traffic controllers, radar operators, airline, military, and private pilots (NASA scientist Richard Haines has a computerized file of UFO sightings by military, airline, private and test pilots that contains 3600 cases going back as far as the early 1970s), astronauts and cosmonauts, police officers, and numerous other professionals and non-professionals, both white-collar and blue-collar, and even clergy.

Many UFO reports have involved combined evidence from eyewitness, photographic, and radar sources. There have been many sightings worldwide in which UFOs were simultaneously tracked both visually and by radar. Civilian eyewitnesses have watched and photographed UFOs from the ground while nearby military installations (or airport air controllers) tracked them by radar. Military pilots, in both the U.S. and other nations, have been scrambled to chase UFOs in response to the objects being picked up by ground radar. In some instances, the pilot's eyeballs and the radar screen blips have provided strong confirmatory evidence of the UFOs strange maneuvering capabilities. Pilots and radar systems have tracked UFOs traveling at unbelievable speeds far in excess of what our best aircraft are capable of achieving, plus making sudden speed changes or directional turns that would be lethal for human pilots.

Finally, I would like to add some of my personal thoughts and opinions into the present discussion of flying saucers. I am in strong sympathy with those professors or scientists who are currently on active duty at universities or other professional institutions, who feel reluctant to become involved or appear associated with any serious UFO investigations. However, I am now retired and feel somewhat freer to stick my ex-professional neck out in expressing my views. While, as a newly self-proclaimed amateur "astrobiologist", my personal inclination is to "root" for the existence of extraterrestrials, my formal training as a scientist and my personal

better judgment makes me keep an open mind with respect to this issue. I have never witnessed a flying saucer (that I know), but would like to do so, if such things exist. Like many scientists worldwide, I find it silly to believe that man is alone in a universe as vast and, possibly, as heavily endowed with potential homes for life-forms, as we now think our universe may be. As far as what I personally believe should be science's stance with regards to the UFO enigma, my response is "do not ignore it, just because others 'giggle', instead study it, using, whenever and wherever possible, those time-honored scientific methods that seem relevant to this rather bizarre phenomenon." While controlled hypothesis-driven laboratory experiments may not work (unless we manage to discover artifacts or space junk possibly left behind by interstellar visitors), some unique kinds of automatic photographic detection or field observation studies might possibly be contrived as an alternative scientific approach. Relatively inexpensive technology for conducting these kinds of investigations has been readily available since the early 1950s. The author would also like to point out that there are definite parallels between the study of UFOs and the study of earthquakes that we scientists need to pay attention to. No one can ever predict when and where a flying saucer will appear or when and where (at least not yet) an earthquake will occur. Earthquake scientists have received extensive funding to study their phenomenon simply because earthquakes kill people, destroy property, and are a major nuisance to mankind's personal and economic well-being. Flying saucers, so far, have been totally benign and nothing more than a curiosity. So, why study them? Study them simply because they may give us tremendous knowledge and insights not only into our own personal human lives but may also provide clues as to why and how we got here. Whether the UFO phenomenon is the result of real alien visitors flying around in real space ships or is some kind of unique psychological or sociological manifestation of our human brains would both make for very interesting and important scientific inquiries.

CHAPTER VII

SOME FINAL THOUGHTS FROM THE AUTHOR

If the reader is still with the author at this point **in** the book, you have my congratulations and sincere thank you. Considering everything we have covered in this book, you may now believe that your brain, like mine, has been boggled by the complexity, immensity, and profound implications of what science has already discovered about life and the universe and what startling new discoveries may still lie ahead in the coming years. This incredible new information suggests that this author and perhaps also the reader, as citizens of our small planet, have led somewhat sheltered lives. Our concept of time has been totally molded by our everyday experiences. Whenever our science friends talk about *deep time*, they lose us. It is hard enough to think back to our childhood years, or to think ahead to our future retirement and golden years, but it is virtually impossible to accept the fact that all of us are directly linked in a continuous non-stop biological manner to those microbe sized ancestors of ours that popped up in the earth's oceans some four billion years ago. When the scientists begin talking about measuring the distances to other stars or other galaxies using the concept of light years instead of miles, they again lose us. To be told that light can travel around the earth seven times in one second might convince most of us that light is definitely faster than "greased lightening". However, to be further told that it takes light from our sun eight minutes to travel to the earth, and it takes 4.4 years for light to get here from the nearest star beyond our own sun would, for most of us, be unimaginable. And, if that same scientist further informed us that light from the most distant galaxies we can see with our best space telescopes required an incredible ***13.2 billion years*** to get here, we might think our friend had finally gone over the deep end or was smoking something he should not. The idea that looking through a telescope at distant celestial objects is "looking into the past" and seeing the objects ***exactly*** as they appeared millions or billions of years ago is indeed bizarre. The concept of a universe of such an immense size is totally beyond comprehension for virtually all of us and that includes, by their own admission, many of our brightest and most experienced scientists. Yet, the very best and most reliable scientific instruments and measurement tools that science has at its disposal all consistently tell us that this new 21st century "picture" of the universe is very real and definitely not a figment of anyone's wildest imagination. It is, instead, the ultimate confirmation that reality sometimes can truly be stranger than fiction!

Most citizens of planet earth are also not able to comprehend the immense power or energy involved in all those geological or celestial "events" such as super-volcanoes, asteroid collisions with the earth, gamma ray bursts from exploding stars, or even explosions of entire galaxies that the earth scientists and astronomers so nonchalantly talk about. Those of us who were children during the Cold War years lived in total apprehension of that horrific thing called the atom bomb. We absolutely could not imagine anything more destructive. Even today, I sometimes experience a touch of anxiety whenever thinking about those "duck and cover" drills that I and other children (Russian as well as American) were forced to practice in elementary school. Yet, the astronomers tell us that the asteroid that struck the earth 65 million years ago that killed the dinosaurs carried the explosive wallop of 10 billion atomic bombs the size of the ones dropped on Japan in WWII. And those of us who witnessed (or more likely watched on TV) the powerful 1980 Mount St. Helen's volcano eruption were totally awe-struck by the amazing power of what we were seeing. Yet, once again, the scientists calmly tell us that if the super-volcano that lies below Yellowstone National Park were to blow its top again, and it almost certainly will someday, the next explosion may be as much as a million or more times more powerful than the Mt. St. Helen's eruption, and might possibly produce a worldwide disaster that could rival what happened to the dinosaurs eons ago. The only saving grace in all this talk of catastrophic geological and celestial events is that they are extremely rare. In fact, they are so rare that mankind's poor mental grasp of the concept of deep time has undoubtedly blessed most of us with immunity from fear or panic type reactions to thoughts of such calamities. However, NASA needs to be continually reminded that there are many more smaller asteroids circling between Jupiter and Mars that are far more likely to strike us than the big one that wiped out the dinosaurs. With time, our cities are growing larger and larger, and remote sparsely populated areas like northern Siberia, that was the 1908 target of a "small" asteroid (which had the explosive power of 1000 Hiroshima atomic bombs) are shrinking. NASA needs to develop a means of detecting and monitoring the whereabouts of threatening asteroids of all sizes in order to also protect us from the smaller potentially "city killer" asteroid strikes.

At least for the author, the most astounding and exciting new revelations to emerge from the life and space sciences in the past 50+ years have been, first, the growing evidence that life appears to be very tenacious and flexible in being able to evolve and prosper in even extremely hostile environmental conditions and, secondly, that planetary systems that might accommodate extraterrestrial or alien life-forms may be relatively common in what we now know is an unimaginably vast universe. Astronomers now estimate that the universe may contain ***at least*** 10^{21} or 1,000 billion billion stars (i.e., 1,000,000,000,000,000,000,000). And most incredibly, the Planet Hunters are now estimating that somewhere between a fifth and one- half of these stars may harbor planetary systems. Of course, not all exoplanetary systems, for various reasons outlined earlier in this book, will be able to host life (or at least our familiar form of carbon-based life). However, if only one in a billion such exoplanetary systems had a single planet that supported life, there would still be approximately 5 trillion inhabited worlds out there. Of course, the vast

majority of such worlds would probably only host something equivalent to earth's earliest single-cell microbial or slightly more advanced multi-cellular life-forms, or possibly other completely exotic alternative forms of life based on something other than water and the carbon atom. Planets that might support advanced life-forms that are in any way analogous or comparable to humans would likely be relatively rare. However, the incredibly vast numbers of potential life friendly locations (exoplanets, or even some habitable moons of exoplanets) that scientists now believe may exist in the universe would strongly suggest that intelligent life-forms (some even with advanced cultural and technological capabilities) while relatively rare, could be quite numerous, although separated from each other by incredible distances (mega-light years).

As described in Chapter 6, mankind now has the technologies needed to observe and study from a distance, using sophisticated space telescopes and other remote sensing devices (e.g., interferometry, spectrometry), the closer exoplanets in our galaxy to determine if any have the potential to host carbon-based life-forms similar to those found on earth. If such planets are identified, the SETI folks will immediately point their radio telescopes towards the planets and start sending as well as listening for radio transmissions (deliberate or unintentional), plus also looking for laser light beams being sent our way. Because of the horrendous distances between us and even our closest intelligent extraterrestrial neighbors, combined with what may be a universal speed limit (i.e., that speed of light thing), it is unlikely that mankind will be launching manned trips to such far-away worlds any time soon. However, unmanned missions could be launched much sooner if mankind is willing to wait the incredibly long times needed for signals from such robotic craft to be returned to earth (albeit to our great-great grandchildren). And, as for the possibility of any extraterrestrials taking the initiative and visiting us first, while a large portion of the world's population believe they already have, most scientists today believe the horrendous interstellar distances involved plus the possible speed-of-light restriction would probably discourage them as much as it will us, at least in the earlier stages of their civilization's lifespan. However, it is entirely possible that some alien neighbors may have been around far longer than us, and may have had the time, plus the temperament and intelligence to develop the technology needed to make such trips as easy as a stroll in the park. It is also entirely possible that mankind, in a few hundred years (or a few thousand), will also find a means of making such trips an inexpensive and normal part of our cultural lifestyle. Starships may eventually replace jumbo jets and vacation (or business) trips to Alpha Centauri and other distant worlds may become as common as today's globe hopping excursions.

Why has Science not Obtained Evidence for Intelligent Extraterrestrial Life?

In 1950, the Nobel prize winning atomic physicist Enrico Fermi was having lunch with a small group of his science colleagues. The group was having an informal discussion related to the

possibility that large numbers of habitable planetary systems might exist in the universe, and some could be home to advanced technological civilizations. At the end of this discussion, Dr. Fermi reportedly turned to the person seated next to him at the table and said something to the effect of "*So, where is everyone?*" While a very simple question at the time, Dr. Fermi's question has, in subsequent years, become the famous ***Fermi Paradox*** that is at the center of the SETI research effort. If there are so many potentially habitable worlds out there, why has science so far not found some evidence of the existence of intelligent extraterrestrial civilizations? In the remainder of this chapter, I would like to offer some of my thoughts on this profound issue. Having been a lifelong hobbyist in astronomy and definitely not a professional could possibly have given me some unique ideas that could be worth presenting. I also believe that my background in psychology and the brain sciences might have provided me some insights into how the equivalent of what we earthlings call "intelligence" might develop as a major functional component of any "nervous systems" that extraterrestrial life-forms may have evolved.

The Fermi Paradox (which, for our purposes, can be simply stated as "*Why has science thus far not been able to detect evidence of advanced extraterrestrial civilizations?*") is now thought by many scientists, including the present author, to have many possible and equally viable solutions (see Stephen Webb, reference 27, at end of book). Many scientists now believe the solution (i.e. answer or resolution) to the Fermi Paradox lies somewhere between two extreme possibilities. At one extreme is the possibility that mankind is actually the only life-form in the entire universe (an idea that almost all scientists now reject) or is the only one that has, so far, managed to reach our so-called advanced level of intelligence. At the opposite extreme is the rather depressing possibility that a large percentage of all civilizations may self-destruct before they are able to reach a level of technological development that would be detectable. Sandwiched in between these two extremes are a large number of alternative solutions that are little more than speculations or educated guesses on the part of our best scientists. I will next describe a few of the more popular of these middle ground speculations before coming back to finish up the present book on a more somber note with a discussion of the two possible extreme solutions to Dr. Fermi's puzzling paradox.

Unfortunately, in spite of the amazing advances that have been made in the past 50+ years in the earth, life, and space sciences, what our scientists think they know is almost entirely based on what they have experienced on earth in their daily and professional lives. They still know relatively little with respect to what may be happening beyond our own atmosphere in the vast regions of space. Our knowledge of life is entirely based on our many years of studying carbon-based life-forms on earth. We have no clue as to whether carbon-based life is common or uncommon on other planets or what bizarre forms of exotic life may be out there that may be totally different from anything our totally biased imaginations can conjure up. Some of the features of earth life may be unique to earth, i.e., may be local or "parochial", and may not exist anywhere else, or if they do exist, they may be restricted to limited locations. Other features of earth life may, on the other hand, be universal in being common to all life everywhere in

the universe. Our scientists, having absolutely no knowledge or experience with any form of extraterrestrial life cannot distinguish between what may be the parochial versus universal features of life. On our planet, we see an absolutely incredible amount of diversity in the physical features of animals and plants that live in different environmental settings. Birds and mosquitoes fly, cows and men walk, snakes crawl, fish swim, gophers both walk and burrow and, of course, amoebae send out pseudopods. Everywhere you look, plants and animals have different sizes, shapes, and colors. Yet, we all recognize them immediately as being earthly life-forms. Why do we recognize that they are all earth critters? Because we grew up with them from childhood and they are part of our normal daily experience.[1] As described in Chapter 3 of this book, our life scientists tell us that, in spite of the vast array of differences in external features, all of these critters are, under the skin (so to speak) virtually identical in terms of how they function biologically.

If earth life is so incredibly diverse, at least with respect to external morphological features, how diverse could extraterrestrial life be? The truthful answer is that our scientists, at the present time, do not have a clue as to how to answer this question. The reason once again, is that scientists have nothing to compare earth life to since we have yet to encounter any bona fide examples of extraterrestrial life. Thus, while life on earth is extremely diverse with respect to external morphological features, it is remarkably non-diverse with respect to its inner biological workings. Trees, ducks, elephants, and eels all look incredibly different but are constructed from the same biological building blocks and use the same basic chemical processes to stay alive and reproduce. What about life-forms on other exoplanets? While extreme external morphological diversity may be a universal feature of life everywhere, what about the internal biological makeups of different life-forms? On earth, the carbon atom is used by all life as the primary structural building block for growth and producing new life while liquid water is the solvent that facilitates all life critical chemical interactions. What about other worlds which may harbor radically different environmental conditions? Will different types of chemistry evolve in response to such diverse environments? Would any life-forms on Saturn's extremely cold moon Titan use liquid methane as its biological solvent since all of this moon's water is frozen solid? It is, therefore, entirely possible that life on other alien worlds may exhibit extreme diversities in terms of both morphological features and inner biological functions. Until scientists have a chance to examine living specimens from a large sample of different alien worlds, they will be totally unable to determine what constitutes the universal as opposed to the regional or local characteristics of life in the universe. In this regard, it is worth noting that many astrobiologists are currently speculating that, because environmental conditions may currently exist on Mars or other places in our solar system (e.g., Europa) that are similar to those

[1]However, in recent years, many of us who watch those fantastic documentary television shows on the Science, History, Animal Planet, or Discovery Channels, or other educational networks, have started seeing absolutely breath-taking high definition real- life images of strange living creatures living in even stranger environments everywhere on our planet. Many of these critters appear so exotic, and engage in such bizarre behavioral antics, that it is hard to believe they are not alien life-forms from outer space.

that earth-bound extremophiles call home, then some of our bacterial citizens might do just fine if transported to these alien locations. Thus, even in our own solar system, it is possible that other locations or environments may exist that could accommodate some forms of carbon-based life similar to those that currently inhabit our planet.

Now, back to Dr. Fermi's perplexing question of why some intelligent extraterrestrial civilization somewhere out there has not accidentally or deliberately made itself known to us. The answer may simply be that life-forms elsewhere are so radically different from us that their biological makeups or associated behavioral activities would not be recognizable to us as being associated with what we think an advanced intelligent life-form "***should be***", or "***should be doing***". Animal biologists tell us that porpoises and elephants are quite intelligent creatures, but they certainly do not reveal this to us in their everyday behaviors. Chimpanzees do, on occasion, act remarkably like us, but why not since they are our closest relatives and share more than 97% of our genetic material. For an intelligent extraterrestrial species to deliberately attempt to contact us and be successful, they would almost have to be virtual clones of our species, at least with respect to their psychological or behavioral makeup. They would have to have sensory capacities (at least vision and hearing) and some kind of neurological system analogous to ours that would allow them to think and act at least reasonably close to how we think and act. *Of course, they would not have to look anything like us in terms of external morphological characteristics*. Such "human ***mental*** clone-like" creatures are likely to be very rare in the universe. However, if there actually are as many as 5 trillion possible habitable worlds out there, such life-forms are probably quite numerous, albeit located far far away.

Therefore (and this is a "big" therefore), many extraterrestrial species who might be intelligent as well as technologically and culturally advanced may exhibit forms of "intelligence" and "advanced technologies and cultures" that are totally different from how mankind defines these characteristics. Our astrobiologists will need to be exceedingly careful about possibly falling into the trap of *anthropomorphism* (a long-winded word that Webster's Dictionary defines as "*the attributing of human shape or characteristics to a god, animal, or inanimate object*"). Thus, one possible resolution of Fermi's puzzle may simply be that we humans are not able to recognize the physical signs or signals that are being sent by far away alien civilizations as being deliberate attempts to communicate with us***. Many ETs may not only be different kinds of biological life-forms but may also utilize methods of communication ("language" systems) that are completely different from anything we humans can imagine***. And it is also entirely possible that some of the distant advanced intelligent species may not share mankind's inquisitive exploratory nature and may simply not be concerned with whether or not we exist. However, in a universe that our scientists now believe is so crowded with potentially life friendly worlds, this author would be willing to wager that there are numerous extraterrestrial life-forms out there that are close enough to us in terms of our form of intelligence, inquisitiveness, and technological competency that we will someday find alien cohorts that we can actually socialize with.

Finally – back to a discussion of the two extreme forms of possible solutions to Fermi's paradox that we mentioned earlier. One possibility may be that mankind is the only advanced intelligent

life-form with technological capabilities in the entire universe. Most scientists today believe this is very unlikely. Of course, in one rather bizarre sense, it is possible that mankind could theoretically be totally unique in the universe, if we were to require that any other extraterrestrial species had to be complete and total 100% clones of our species. It is said that no two snowflakes ever look exactly the same, and the same would almost certainly be true for human-like critters elsewhere in the universe. However, most scientists today believe that there are probably at least some extraterrestrial species out there that, while not being our "identical twins" might possibly be our "fraternal twins" or even distant cousins, not in terms of physical appearance of course, but in terms of how they think and act.

With regards the possibility that mankind may be prodigy-like in being the first intelligent life-form with technological skills to develop in the universe, many but not all scientists also reject this idea. If life on our planet is typical, and we presently have absolutely no evidence that would allow us to even speculate whether it is or is not, it took approximately 4.0 billion years for life on earth to evolve from the microbial to the human stage. And since scientists currently estimate our universe is close to 13.7 billion years old, it would appear that there probably would have been more than adequate time for other intelligent species to have come and gone before us. However, since the creation of heavier atomic elements (carbon, oxygen, nitrogen, etc) during earlier supernova explosions of giant or super-giant stars is a critical prerequisite to allow the formation of both planets and life, astronomers are not sure how quickly after the Big Bang sufficient amounts of heavier elements would have become available to permit life to begin forming. Astronomers tell us that most modern day interstellar dust clouds, at least in our galaxy, contain only about 2 to 3 percent elements that are heavier than hydrogen and helium. This small amount was obviously sufficient to support the development of life on our planet. However, since it might have required many billions of years for this concentration level to have been achieved, a few scientists speculate that mankind could possibly be one of the first advanced species to have developed. Most scientists, in contrast, believe that the majority of ET civilizations would very likely be older than our civilization, with many being thousands, millions, or even billions of years older than us. Remember, mankind as a "technological society" is a virtual newborn. According to Dr. Sagan's 364-day long "Cosmic Calendar" analogy of life on our planet (described in Chapter 4) human civilization is just a ***few seconds old!*** Thus, the chances of any extraterrestrial civilization being younger than ours is extremely small (almost nil) in contrast to the probability of their being older.

Are Intelligent Life-Forms Vulnerable to their Primal Emotional Natures?

Unfortunately, it is now time for me to address the final possible extreme solution to the Fermi paradox, and that is that many advanced extraterrestrial civilizations may not be able to survive long enough to be detected. Once again, unfortunately, our psychologists, sociologists, and other

behavioral scientists have only one form of advanced society to study (i.e. "human civilization as we know it"). On our planet, mankind evolved from a long line of predatory ancestors. In the jungle, predators spend much of their time looking for other animals to kill and eat or in taking evasive actions to avoid being eaten by other predators. The law of the jungle that only the fittest survive forced nature to implement evolutionary strategies that favored those creatures that had the stronger aggressive tendencies and the more effective cunning behaviors when it came to effectively and efficiently finding and killing their victims, plus successfully avoiding being eaten. In this regard, early man was no different than his four-legged adversaries, the bears and the tigers. The advent of this predatory lifestyle was undoubtedly the single greatest factor that triggered the rise of the behavioral attribute called "intelligence" in the different animal species. In a very real sense, intelligence and aggressiveness are strong inter-dependent consequences of early man's (and other animals) being forced to pursue a predatory lifestyle in order to survive. Neuroscientists tell us that the brains of modern man (**Figure 7-1a**) and the brains of all modern day predatory animal species (e.g., snakes, alligators, sharks, lions, bears, etc.) share similar complex neuronal circuits (i.e., the so-called sub-cortical *limbic* regions of the brain) that control its owners emotional states (anger, fear, love, hate, competitiveness, aggressiveness, etc.). While the limbic area of the brain is a very primitive structure that has been present in all animals from the earliest amphibians and reptiles up to man, there is another region of the brain that is

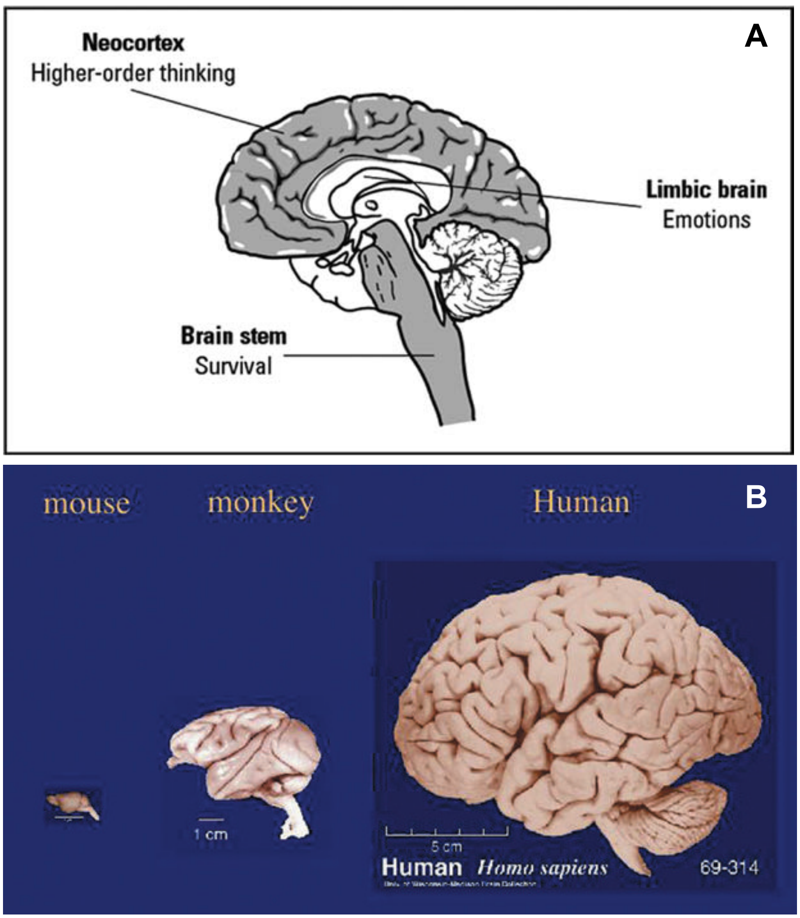

Figure 7-1 - (**A**) depicts the relative location of the Neocortex and the Limbic system in man's brain (Reprinted with permission from Laura Erlauer, Brain-Compatible Classroom, Association for Supervision and Classroom Development, 2003), while (**B**) shows the large increase in the size of the neocortex in the mammalian line of evolution leading to man (Image credit: http://www.nibb.ac.jp/brish/Gallery/cortexE.html).

totally unique to man's line of evolution, i.e., to us breast-feeding mammals. This brain region, which is known as the *neocortex*, is located on top of the sub-cortical limbic area of the brain. In mammals, this cortical area has steadily grown larger and larger (**Figure 7-1b)** in relation to other areas of the brain (including the limbic area). In the primate line of evolution, and especially in apes and humans, this cortical area has grown quite large. Scientists believe the neocortical part of the brain houses the complex neural circuitry that controls higher level intelligence. Thus, while man is supposedly the most intelligent life-form on planet earth, he still possesses a very active sub-cortical brain region, the limbic area, that controls his emotions, and especially his competitive and aggressive nature.

Therefore, man as well as all other mammalian species, possess two distinct and separate areas of the brain, one of which, the neocortex, controls intelligent behaviors and the other, the sub-cortical limbic areas, that controls the emotional side of its owners life. Both of these brain regions evolved in direct response to our early ancestors' need to pursue a predatory lifestyle in order to stay alive. Unfortunately, there is more than a little evidence that, in man, this evolutionary history may have created some kind of "Jekyl and Hyde" paradox in its own right. Being intelligent and being aggressive are both good things if they are strictly used to survive in the wild, as was the case for our early ancestors. However, when mankind transitioned from a predatory jungle lifestyle, where it was every man for himself, to a cooperative civilization form of lifestyle, man's intelligent and aggressive sides may have started to conflict rather than reinforce each other. In a cooperative civilized world where it was now possible to share the workload with other tribal members and not have to continuously engage in hunting, killing, running, and hiding to survive from day-to-day, some individuals could leave the basic routine chores (gathering food, tending gardens, etc.) to others and engage themselves in inventing new and better tools to make life more fun and comfortable for everybody as well as to protect the home team (tribe) from the aggressive assaults of competing tribes. Man started to build weapons, first clubs, then bows and arrows, then guns, and eventually nuclear weapons. In the meantime, man's brain still housed the same old neuronal structures that had facilitated his survival for millions of years. Now, when his sub-cortical limbic system threw him into an aggressive emotional state, rather than trapping a rabbit and eating it, he might beat his wife, rob the corner liquor store, or, eventually, push a button to unleash rockets carrying nuclear warheads to kill his tribe's enemies on the other side of the world.

Thus, it is possible that the "ugly" but apparently necessary behavioral attribute we call *predation* may be a very common feature of the early stages of life's evolutionary development in many other regions of the universe as well as here on our own planet. One possible solution to Fermi's famous paradox may simply be that many advanced extraterrestrial civilizations are unable to control their own inherent primal aggressive nature sufficiently to prevent them from destroying themselves with the technologies that their intelligent nature has allowed them to develop. And, unfortunately, it is not only the invention of weapons of mass destruction by emotionally unstable humans or extraterrestrials that can lead to the premature demise of

budding civilizations, it is also the misuse or abuse of their home planet's natural resources that can just as effectively destroy a civilization. On planet earth, mankind's ignorance or greediness (or both) is now threatening our planet's survival as evidence continues to mount that burning fossil fuels and destroying forests may in the not too distant future shove our world into a runaway greenhouse effect that could burn up all life on earth.

So, what is the solution to this dismal state of affairs with respect to mankind's possible future? The present author has no answer for this dilemma and, apparently, neither does anyone else. Is religion the answer? Could be, but only if mankind totally reevaluates and revamps the concept of what it means to be religious. Historically, religion has been used as much to destroy as to comfort the lives of those who practice it. Wars have been fought both to eliminate tyrants as well as destroy infidels and heretics. Cultural and religious intolerance has always been as much an excuse for tribal warfare as disputes over territorial and food resources, and the single largest expense item in most of the major national economies continues to be building and maintaining weapons with which to destroy our fellow humans. Will discovering that man is not alone in the universe act to solve our problems? Maybe - maybe not. But it might just help. Perhaps, what mankind needs is not a religious reawakening but a totally new form of "spiritual" awakening. Our egos and our basic aggressive instincts, combined with our intelligence, have now led us to the brink of disaster. Perhaps, we need to step back, take a deep breath, and look at the larger reality that we are not special in any way (***NOT*** the center of the universe) and very likely also not alone in the universe, and that our emotional energies and intelligence could be channeled in far more productive and enjoyable directions than the one that is currently threatening to destroy

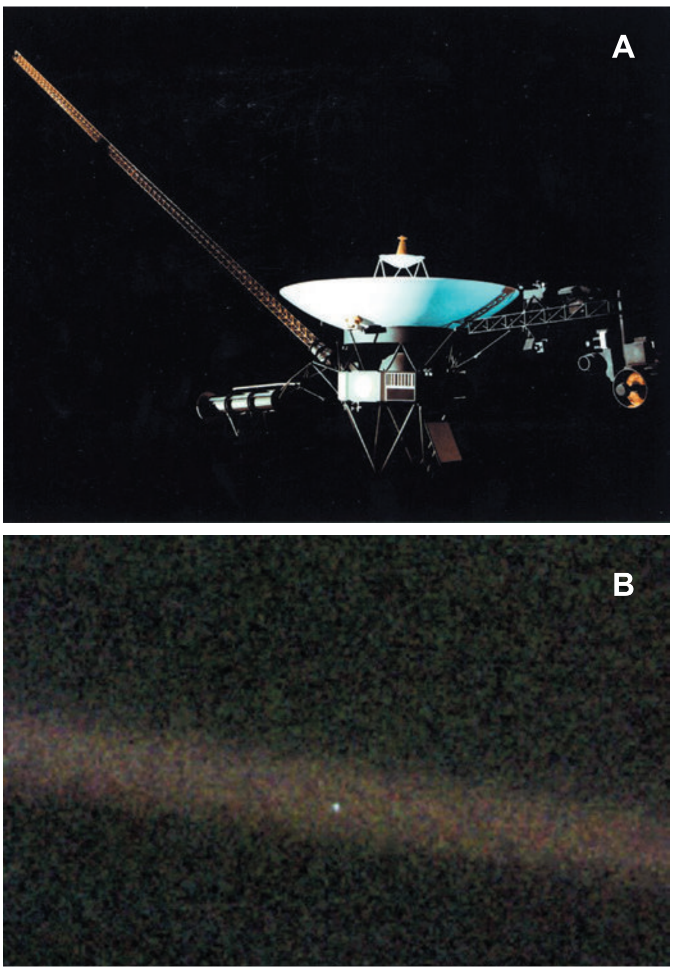

Figure 7-2 - **A** shows an artist's drawing of one of the two NASA Voyager spacecrafts that were launched in 1977 and are now heading out of our solar system, while **B** presents the last faint photograph that Voyager I was able to take of the earth as it continued on its journey into interstellar space. (Image credit: NASA/JPL-Caltech)

us. Instead of continuing to bankrupt the world's economies by building weapons of mass destruction, why not channel these vast resources into educating our children, overcoming poverty and hunger, pushing medical research to make people healthier, developing the arts and sciences to make people happier, and even reaching for the stars to find out who else is out there to visit or communicate with. **Figure 7-2a** shows one of the two ***Voyager*** unmanned spacecraft that were launched by NASA in 1977 to photograph and study the outer planets. Both spacecraft are presently beyond the orbits of Neptune and Pluto and are predicted to totally leave our solar system in another 5 years or so (sometime possibly in 2015). As it passed Pluto, ***Voyager* 1** "looked back" and took a last snapshot (**Figure 7-2b**) of its home planet. The extremely small blue dot located in the center of the photograph is the earth. This is the best image the powerful telescopes and cameras onboard the spacecraft could manage since planet earth was now almost four billion miles away and earth was steadily fading from view. This tiny blue dot in the vastness of space is our home, and is the only home mankind has ever known. We must learn to share and cherish it or we will perish.

FURTHER SUGGESTED READINGS

In the hopes that the reading of the present book has triggered the reader's imagination and interest in the exciting new scientific field of Astrobiology, I will now list a number of books that I would recommend as sources for additional information. Before sitting down in front of my word processor to begin the actual writing of the present book, I devoted almost two years to reviewing the latest published literature in this field to make sure my knowledge was up-to-date. In what follows, I will list each of 27 different books that I would strongly recommend to readers who now want to learn even more about this exciting new science. The references cited here, of course, are only my personal choices and should not be taken in any way as necessarily the "best" choices available. Professional astrobiologists, or even "amateur" astrobiologists other than me, might or might not like some of the references cited here and might recommend others. The reader should definitely be open to suggestions for further reading from any friends or associates who may be knowledgeable in this new field of astronomy. Local universities or colleges may, in fact, offer courses in these areas that the reader could arrange to attend. Also, members of local amateur astronomy clubs might also be helpful in suggesting reading materials.

(1) Eric Chaisson & Steve McMillan, ***Astronomy Today, 3rd Edition***. Upper Saddle River, New Jersey: Prentice-Hall, 2000 (more recent editions available)

This book is designed to be a general overview of the field of astronomy for undergraduate college students who are not science majors. I highly recommend it to broaden the reader's knowledge of astronomy beyond the "search for extraterrestrial life" focus of the present book.

(2) Ray Spangenburg & Kit Moser, ***The Life and Death of Stars*** New York: Franklin Watts, 2003.

Short - only 108 pages - but an excellent and easily understood general overview of stars and their life cycles.

(3) Jeffrey Bennett, Seth Shostak, & Bruce Jakosky, ***Life in the Universe***. San Francisco: Addison Wesley, 2003.

The book is a comprehensive overview of the field of Astrobiology and all its associated fields, e.g. the space, earth, and life sciences. The book is designed for undergraduate students who are non-science majors or just beginning their study of the astronomy and

astrobiology fields. The book is also an excellent resource for general readers. I read it from cover-to-cover three times.

(4) Don Berliner, ***UFO Briefing Document: The Best Available Evidence,*** New York; Dell Publishing, 1995.

Although many books on the UFO phenomenon are not worth the paper they are written on, there are a few that do attempt to convey to general readers an accurate and unbiased overview of this potentially important topic area. This book is one of those few.

(5) David Darling, ***Life Everywhere***. New York: Basic Books, 2001.

A relatively short, only 206 pages, but very informative and entertaining general overview of Astrobiology, written by a serious scientist in the field.

(6) Lewis Dartnell, ***Life in the Universe: A Beginner's Guide***. Oxford, England: Oneworld Publications, 2007.

Another relatively short but easily understood overview of Astrobiology.

(7) Armand Delsemme, ***Our Cosmic Origins: From the Big Bang to the Emergence of Life and Intelligence***. Cambridge: Cambridge University Press, 1998.

(8) Christian de Duve, ***Life Evolving***, New York: Oxford University Press, 2002.

Dr. De Duve is a Nobel laureate in the life sciences who has an uncanny ability to make the complex subject of evolution and life an entertaining and informative experience for general readers.

(9) Iain Gilmour & Mark Sephton (Eds.), ***An Introduction to Astrobiology***, Cambridge: The Open University, 2003.

(10) Mahlon Goagland & Bert Dodson, ***The Way Life Works: The science lover's illustrated guide to how life grows, develops, reproduces, and gets along,*** New York: Three Rivers Press, 1998.

A medical doctor/researcher and a very talented medical artist teamed up to produce an excellent "picture book" guide to how life works. I recommend this book to anyone interested in this fascinating topic.

(11) Tony Hallam, ***Catastrophes and Lesser Calamities: The Causes of Mass Extinctions.*** Oxford, Oxford University Press, 2004.

(12) J. Allen Hynek, ***The UFO Experience: A* Scientific *Inquiry,*** New York: Marlowe & Company, 1972, 1998.

Dr. Hynek was an astronomer and a UFO skeptic when first asked to direct the U.S. Air Force's "Project Bluebook" inquiry into UFOs. Several years later, when Project Bluebook was shut down by the Air Force, Dr. Hynek left the project as a non-skeptic. This book recounts Dr. Hynek's personal experiences and thoughts on this very controversial subject matter, which all general readers should read.

(13) Bruce Jakosky, ***The Search for Life on Other Planets***, Cambridge; Cambridge University Press, 1998.

(14) Bruce Jakosky, ***Science, Society, and the Search for Life in the Universe,*** Tucson: Arizona University Press, 2006.

The discovery that we are not alone in the universe will be a profound eye opener for all of us. In this book, Dr. Jakosky discusses just how profound and life-changing that experience may be.

(15) Kirk Johnson & Richard Stucky, ***Prehistoric Journey: A history of life on earth,*** Boulder: Roberts Rinehard Publishers, 1995.

(16) Andrew H. Knoll, ***Life on a Young Planet: The first three billion years of evolution on earth.***, Princeton: Princeton University Press, 2003.

(17) Sidney Liees, Elisabet Sahtouris & Brian Schllimme, ***A Walk Through Time: From Stardust to Us,*** New York: John Wiley & Sons, Inc., 1998.

(18) Philip Platt, ***Death from the Skies: These are the ways the world will end...,*** New York: The Penguin Group, 2008.

In spite of the rather "attention getting" title, this book is designed to inform and not tantalize the reader. Dr. Platt does an excellent job of describing the different possible celestial calamities that could happen to planet earth.

(19) Kevin Plaxco & Michael Gross, ***Astrobiology: A Brief Introduction***, Baltimore: The Johns Hopkins University Press, 2006.

(20) Stanley Schmidt & Robert Zubrin (Editors), ***Islands in the Sky: Bold new ideas for colonizing space.*** New York: John Wiley & Sons, Inc., 1996.

While the idea of manned interstellar space travel and colonization of other worlds by humans now seems very far-fetched, some serious scientists believe it will eventually happen if mankind does not destroy itself first. This book is not science fiction, but instead presents the sincere educated guesses and speculations of some of our best rocket scientists.

(21) Seth Shostak & Alex Barnett, ***Cosmic Company: The search for Life in the universe,*** Cambridge: Cambridge University Press, 2003.

(22) Gloria Skurzynski. ***Are We Alone? Scientists search for Life in space.*** Washington, D.C.: National Geographic Society Press, 2004.

The book is an excellent non-technical overview of the history and current research activities of the SETI investigators.

(23) Peter B. Ward & Donald Brownlee, ***Rare Earth: Why complex life is uncommon in the universe***, New York: Copernicus Books, 2004.

(24) Peter Ward, ***Life as We Do Not Know It: The NASA search for (and synthesis of) Alien life,*** London: Penguin Books, 2005.

(25) Peter Ward & Donald Brownlee, ***The Life and Death of Planet Earth:*** New York; Henry Holt and Company, 2002.

(26) Peter Ward, ***Under a Green Sky,*** Washington, D.C.: Smithsonian Books, 2007.

This book is an excellent description of what natural calamities may threaten man's future if we do not come to our senses and switch to clean energy alternatives and stop destroying forests and polluting our atmosphere with deadly carbon dioxide fumes.

(27) Stephen Webb, ***If the Universe is Teeming with Aliens.....Where is Everbody? Fifty solutions to Fermi's Paradox and the problem of extraterrestrial life.*** New York: Copernicus Books, 2002.

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